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PREFACE

The interdependence of theory and practice cannot be ignored without inflicting injury on both; and he is but a poor friend to either who undervalues their mutual co-operation.

Rt. Hon. A. J. Balfour at the British Association.

THE objects of the present volume are to supply the admitted need for an up-to-date and detailed exposition of the telegraph practice of the British Post Office and also to provide for the requirements of the Departmental and City and Guilds' examinations in the subject. With the latter object in view I have furnished a plenitude of fully worked numerical examples and have included elementary accounts of galvanometers, battery testing, and the Wheatstone bridge. After anxious and careful consideration in the light of an extensive teaching experience I have deemed it best to avoid the use of mathematics, and I am satisfied that the more elementary method adopted will make the work accessible to the far larger and wider circle of readers who most need the information I have sought to convey.

Generally speaking, the history of the subject and the names associated with the various advances therein have been omitted since adequate discussion would have increased the bulk of the work beyond the limits of a single volume and would, of necessity, have involved a considerable increase in the cost of publication—a result which I should have greatly deplored.

The purpose of the introductory chapter is rather to indicate the general principles of electricity and magnetism than to explain them at length, the number of sources from which an account may be obtained being well nigh unlimited. I believe, however, that a brief statement of the fundamental laws of these sciences will be of considerable value to many.

Batteries, apparatus, systems, and the construction of aërial and underground lines are successively considered, opportunity being taken to deal with various principles and phenomena as the need for their application arises. It will be observed that the Murray automatic system occupies a position in the Appendix instead of in its rightful place in the body of the book, but this is entirely due to the fact that the preparation of the present volume has occupied nearly four years. A similar remark applies to the description of the latest standard arrangements for quadruplex circuits (Section E), and to the now important subject of superimposing telegraph circuits upon telegraph and telephone loops (Section C).

A few problems dealing with the capacity of lines and cable cores have been provided under Section F of the Appendix for the benefit of students preparing for the Honours Grade Examination in Telegraphy held by the City and Guilds' Institute.

Submarine and Wireless telegraphy have been omitted owing to considerations of space and to the fact that each subject already possesses an extensive literature of its own. There are many most interesting telegraph systems which have not yet sufficiently materialized for the every-day work of a large telegraph office, and here again the space factor, and the avowed object of the book, have prevented their inclusion. Since the Delany multiplex has passed from the sphere of British telegraphy the Chapter which had been written upon the subject was excised.

The Journal of the Proceedings of the Institution of Electrical Engineers, the *Electrical Review* and the *Electrician* have naturally been freely consulted during the preparation of the work.

I beg to acknowledge my indebtedness to:—Sir Samuel Boulton, Messrs. J. E. Kingsbury, E. J. Chambers, A. H. Atkins, D. Murray, W. S. Steljes, and F. Crawter; also to the following gentlemen of the Post Office Department:—Messrs. M. F. Roberts, J. W. Willmot, H. R. Kempe, H. Hartnell, T. F. Purves, J. R. M. Elliott, C. C. Vyle, G. F. Mansbridge, W. Moon, H. Wilson, H. A. Miles, W. J. Stubbs, W. E. Twells, R. Ianson, E. I. T. Newton, and A. Q. Ellery.

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The material assistance which I have received has been so freely and so willingly given that it seems almost invidious to make distinctions, but owing to the larger demands I have made upon Mr. Hartnell, I feel that it is impossible to allow this opportunity to pass without a definite expression of my warm appreciation of the numerous and valuable suggestions which he has made whilst reading the proof sheets. To Mr. Ianson, also, I desire to express my cordial thanks for the services which he has rendered to me in reading and criticizing both the original manuscript and the proof sheets.

With the exception of the manufacturers' blocks, the drawings for the illustration of the text have been prepared by Mr. O. P. Moller, to whom my thanks are conveyed for the care and thought which he has bestowed upon the work.

The utmost care has been taken in compiling the work to ensure that the various descriptions shall accord with the latest practice as it at present exists under the direction of Mr. Gavey, the Engineer in Chief to the Post Office, and it is to be hoped that no important error has escaped detection, but should the hope prove vain, I shall welcome and appreciate an intimation addressed to me under cover to the Publishers.

T. E. H.

London, November, 1905.

CONTENTS

INTRODUCTION

THE FUNDAMENTAL PRINCIPLES OF MAGNETISM AND ELECTRICITY, AND UNITS

PAGE

Static electricity—Potential—Calculations in electro-statics—Magnetism—Lines of force—Magnetic induction—Quantitative values of magnetic effects—Voltaic electricity—Conductors and insulators — Units—Ohm's law — B.A. and standard units—Other electrical units 1-17

CHAPTER I

PRIMARY CELLS

Simple cell—Local action—Internal and external circuit—Polarization — Daniell battery—Chemical action — Practical notes—Leclanché cells—Various forms—Chemical action—Fuller's mercury bichromate—Chemical action—Practical notes — Three-pint bichromate — Dry cells — Gassner cell — E.C.C. cell — Hellesen cell — Obach cell — Standard cells — Clark cell—Specification for Clark cell—Daniell standard cell—Characteristics and employment of cells used by the Post-Office—Tabulated comparison of cells used by the P.O. —Ideal cell 18-42

CHAPTER II

CALCULATIONS IN CONNECTION WITH CIRCUITS AND CONDUCTORS

PART I. — Arrangement of cells : —

Size of Cell—Three methods of joining up cells—Cells in series—Cells in parallel—Cells in multiple arc—Method in which to join up cells under different circumstances—Cells wrongly joined up and special arrangements—Number of cells to furnish a given current—Special cases 43-55

PAGE

PART II.—Joint resistance and division of current :—

Resistances in series—Conductance—Mho—Several paths in parallel—Several paths of equal resistance in parallel—Two paths in parallel—Complicated circuits—Division of current between several paths in parallel—Division of current between two paths in parallel—Batteries in multiple arc joined to paths in parallel—P.D. and E.M.F. 55-63

PART III.—The resistance of wires of varying dimensions :—

Factors determining the resistance of a conductor—Problems on the resistance of wires of varying lengths, areas and diameters—Resistivity—Wires of varying length and weight—Ohm-mile constant—Percentage conductivity—Resistance of one foot grain of wire—Wires of varying weight and diameter—Application of laws to cells—Effect of temperature upon resistance and capacity—Effect of pressure upon resistance . 63-75

PART IV.—Electromagnets :—

Magneto-motive force, reluctance and flux—Permeability—Magnetizing force of solenoid—Resistance and figure of merit—Problems on the winding of electromagnets 75-80

CHAPTER III

GALVANOMETERS, RESISTANCE COILS, AND SHUNTS

GALVANOMETERS—Introductory—Tangent galvanometer—Helmholtz or Gaugain galvanometer—Tangent of an angle—Absolute galvanometer—P.O. tangent galvanometer—Skew scale—Parallax error—Differential winding—Controlling magnet—Number of convolutions—Horizontal galvanometer—Reflecting galvanometers — Damping — Types of Kelvin galvanometer—Astatic needles and systems—D'Arsonval galvanometer—Ballistic galvanometer—Figures of merit—Definition of sensitiveness — RESISTANCE COILS — Boxes of various types—Type of wire to be used—Temperature coefficients — Gauge of wire — Rheostats—Double winding — GALVANOMETER SHUNTS—Principle—Laws—Compensating resistance — P.O. tangent galvanometer shunts — Problems—Universal shunt—Galvanometer constant—Taking constant—Constant of reflecting galvanometers 81-127

CHAPTER IV

BATTERY TESTING

MEASUREMENT OF E.M.F.—Direct deflection method—Equal current method—Wiedemann's method—Potentiometer method—Rayleigh's compensation method—Modern forms of potentiometer — Summary of methods of measuring E.M.F.s—

PAGE

MEASUREMENT OF INTERNAL RESISTANCE — Half-deflection method—Diminished deflection direct method—Thomson method—Wheatstone bridge method—Muirhead's method—Resistance of secondary cells — EDEN BATTERY TESTING INSTRUMENTS—E.M.F. test—Internal resistance test—Proof of principle—Battery testing board 128-161

CHAPTER V

SINGLE CURRENT SYSTEMS AND RELAYS

Earth return—Earth connection—Electromagnet—North pole of solenoid—Residual magnetism and retentivity—Sounder—Single current key—Single current galvanometer—Up and down stations—Direct sounder connections—Intermediate stations—Direct writer—Open and closed circuit working—THE SINGLE NEEDLE SYSTEM—Varley's coils—Spagnoletti's coils—Figure of merit—Neale's coils—Commutator—Skeleton connections of commutator—Connections of single-needle circuit—Resistance and battery power—Advantages of system — Tracing instrument faults — RELAYS — Relaying sounder—P.O. non-polarized relay B—Relays used in telephony—Translating or "D" relays—Polarized relay — P.O. standard relay—Neutral relays—Resistance and figure of merit —"C" type relays—Siemens relay—Test for differentiality—Design of relays—THE DOUBLE PLATE SOUNDER—Plate sounders —Commutator—Connections—Up and down offices—Prevention of sparking at relay contacts—Earlier form of commutator —Arrangement of apparatus—Adjustment—Faults—Battery power and current required—THE SINGLE CURRENT SOUNDER—Connections—Faults—Adjustment—Coils in parallel or series—Direct *v.* single current sounder—Form of battery—Local inker —Use of "D" relays 162-210

CHAPTER VI

CAPACITY, CONDENSERS, AND THE DOUBLE CURRENT SOUNDER

Condensers—Capacity—Electro-static lines of force—Electro-static explanation of capacity—Dimensions of condensers—Specific inductive capacity—Capacity of plate condenser—Condensers in parallel and series—Condensers used in telegraphy —Insulation of condensers—Specification of insulation and capacity—Condenser discharge—THE DOUBLE CURRENT SYSTEM —Advantages of double current system—Reverse current and charge upon the line—Detailed explanation—Other advantages of the double current system—Double current key—Connections of double current sounder—Path of current—Use of double current set for single current working—Faults—Battery power and current required 211-230

PAGE

CHAPTER VII

THE DIFFERENTIAL DUPLEX

THE SINGLE CURRENT DUPLEX—Systems of duplex working —Opposition method—Path of current—Intermediate position of keys—Use of non-polarized relays and direct working—Differential galvanometer—P.O. or combination method of duplex working—Path of current—Numerical values of current in each part of the circuit—Intermediate position of keys—Skeleton connections required for single current duplex —Duplex switch—Connections of duplex switch—Balancing—Faults—Useful facts—Direct writer duplex—Difficulty in working very short circuits—Battery power and current required—THE DOUBLE CURRENT SOUNDER DUPLEX—Conditions for double current duplex working—Skeleton connections—Effect of capacity of line—Graphic representation of charge upon a line—Paths of line and compensation circuit charges and discharges—Summary of line and compensation circuit charges and discharges—Arrangement of compensation circuit for balancing long lines—Effects of defective capacity balance—Retardation and condenser coils—Capacity balance may differ at the two stations—Connections of duplex set—Resistance balance — Capacity balance — Faults — Battery power and current required 231-266

CHAPTER VIII

THE QUADRUPLEX

Principle—Skeleton connections—Value of current under various conditions—"B kick"—Relaying sounder—Condenser "B" side—A key—B key—Earthing arrangements—Quadruplex resistance blocks—Use of 6-terminal reversing keys—Effects of short circuit and disconnection in intermediate positions of the keys—Connections—Universal principle of working—Balancing—Adjustment—Decrement working—Use of bridging coil—Other quadruplex systems—Faults—Current required and type of battery used—The diplex—Wheatstone upon the A side 267-290

CHAPTER IX

THE WHEATSTONE AUTOMATIC SYSTEM

General—PERFORATOR—Operation of punches—Paper feeding device—Punches—Auxiliary appliances—Perforator adjustment—Pneumatic perforators—TRANSMITTER—The divided

PAGE

lever—Motive power—Arrangement of the reciprocating rods and the divided lever—Action of transmitter in signalling a word—Summary of action of transmitter—Magnetic bias transmitter—Transmitter bias—Arrangement for regulating the speed of the transmitter—Action of fan in maintaining uniformity of speed—Stopping and starting lever—"Bolting" of transmitter—Speed of slip—THE RECEIVER—Principle—Inking arrangements—Double slip drawer and bell—Motor and train—Winding of coils—Adjustment—Spring receiver, speed of slip and figures of merit—SHUNTED CONDENSER, SELF-INDUCTION AND TIME CONSTANT—Use of shunted condenser to balance self-induction—Action of shunted condenser in Wheatstone working—Adjustment of shunted condenser—Action of shunted condenser upon a very short line—Resistance of sending circuit—Transmitter switch—Connections of a full Wheatstone set—Adding a transmitter to a key-worked circuit—Substitution of a receiver for a relay—THE WHEATSTONE DUPLEX—Differential duplex with signalling and reading condensers—News circuits and battery power required—THE STEVENS AUTOMATIC . 291-329

CHAPTER X

THE BRIDGE DUPLEX

Use—Advantages of the system—General principle—Intermediate position of the key—Resistance of the arms or duplex coils—Double current working—Both keys at rest—One key only depressed—Both keys depressed—Intermediate position of the key—Compensation circuit and balancing—General arrangements—The signalling condensers—Summary of the action of the signalling condensers—Reading condenser—Connections—Self-inductance of apparatus at the sending station—Calculation of the current in each part of the circuit—Calculation of battery power—Type of battery employed . . 330-345

CHAPTER XI

THE WHEATSTONE A.B.C. AND STELJES RECORDER

WHEATSTONE A.B.C.—Introductory—General principle—A.B.C. indicator—Clockwork bell—Combined indicator and bell—The generator—The communicator—Arrangement of keys and endless chain—Operation of contact maker and pawl arm—Connections of A.B.C. sets (ordinary or series working)—Leak-working—THE STELJES RECORDER—General principle—Type-wheel escapement — Printing arrangements — Figure changing cam—General arrangement and slip-feeding device—Synchronizing lever—Connections 346-369

PAGE

CHAPTER XII

THE HUGHES

Introductory—General principle—Hughes electromagnet—Motive power and governor—Earthing of the line immediately the armature rises—Electromagnet disconnected whilst the armature is replaced—Keyboard—Chariot—Rejector—Number of characters which can be printed per revolution—Type wheel axle—Change-over from letters to figures—Functions performed as the result of releasing the armature — Printing axle entrained—Replacement of the armature—Disconnection of the electromagnet—Printing axle cam—Correction for synchronism—Paper movement—Zero-adjusting lever—Connections — Manipulation — Conventional signals — Preparations before connecting the instrument to line—Adjustment for equality of speed—Effects of retardation—Hughes duplex—Duplex resistance coils—Electromagnetic leak—Connections 370–401

CHAPTER XIII

TELEGRAPH SWITCHING SYSTEMS

Introductory—THE CONCENTRATOR—Introductory — Indicator relays—Drop indicator—Switch springs or jacks—Circular peg—Cords—Connections and working of concentrator—"Time" arrangements—Battery power and balancing resistances—Single and double current circuits connected to the switch—General arrangement—LONDON METROPOLITAN SWITCHING SYSTEM—Number of circuits required — Multiple switch—Need for engaged test—Method of operating—Polarized sounder—Indicator key—Other apparatus—Connections of a disengaged circuit—Two circuits connected together—Clearing signal—Speaking apparatus—Collecting offices—Engaged test—Intermediate offices—Provincial switching system—Other details—CENTRAL BATTERY DUPLEX 402–427

CHAPTER XIV

SECONDARY CELLS

Introductory — Planté and Faure cells — Chemistry of secondary cells—Hydrometer evidences for and against the double sulphation theory—Polymerization theory—Expansion of the active material on the positives—D.P. cell—Chloride cells—Modifications of the chloride cell—Exide negative—E.P.S. cells—Hart cells—E.M.F. on charge and discharge—Internal resistance and temperature—Insulators—Electrolyte—First charge—Treatment of cells 428–453

PAGE

CHAPTER XV

UNIVERSAL BATTERY SYSTEM, THEORY AND POWER ARRANGEMENTS

Introductory—General principle—Theory of system—**Universal** working with primary batteries—Voltmeter—**Ammeter**—Voltages required—24^{v} sets—Necessity for 900$^{\omega}$ **sounders**—Main sets—General scheme of fuses—Battery room—**Main** fuses at the cells—Switch cabinet—Main charging **switches**—Main distributing cabinet—Distribution and fuse **case**—Original secondary cell system—Distribution—Charging **arrangements**—Provision of charging current—Electromagnetic **cut-outs**—Other apparatus required—Size of cells . . 454–485

CHAPTER XVI

ALTERATIONS IN THE CIRCUIT CONNECTIONS FOR UNIVERSAL BATTERY WORKING

Principle—Single needle—Summary of alterations to single needle circuits—Up and down offices—Intermediate offices—Use of resistances between the fuses and instruments—Double plate sounders—Summary of alterations to double plate sounder—Up and down offices—Intermediate offices—Single current sounders—Intermediate offices—Single current duplex—Double current sounders—Double current sounder duplex—Wheatstone—Special circuits—Wheatstone duplex for special circuits—Wheatstone duplex (differential system)—Bridge system—Quadruplex—Quadruplex with Wheatstone on the A side—Test box speaking set—Universal working with primary batteries 486–511

CHAPTER XVII

REPEATERS

Working speed of a circuit—Battery resistance—Distributed leaks and inductance coils—Capacity and resistance of various types of line—Theory of repeater—Principle of simplex repeater—Automatic switch—Simplex repeater—Path of current—Adjustments—Faults—Duplex repeater—Duplex repeater for cable circuits—Forked repeater—Path of current—Sounder silencer—Circuit silencer—External connections of repeater board—Battery power—Hughes repeater—Quadruplex A side relayed—Pole-changer—Path of current—New Quadruplex A side relayed—Quadruplex repeater . . . 512–550

PAGE

CHAPTER XVIII

THE TEST BOX AND PROTECTIVE DEVICES

PART I.—The Test Box :—

Principle and general arrangement—Arrangement of circuits and test box changes — Terminal circuits — Intermediate circuits—Through circuits—To earth a wire—To loop wires—To reverse—Metallic circuit—To divide a wire—To fork wires—To join through—To tap a circuit—To cross instruments or circuits—Test box for small offices—Battery test box—U-link type of test board—Switch spring type of test board—Principle—Cross-connecting facilities—Test box changes and transfer circuits—Special intermediate sets—Looping strip . . 551–566

PART II.—Lightning protectors :—

Theory—Reel protector—"A" and "B" protectors—"C" protector—"D" protector—Vacuum protector—Tablet protector—Protectors of Saunders and Lodge—Position of protector and formation of an inductance spiral 566–574

PART III.—Protection from power circuits :—

Guard wires—Use of india-rubber gloves—Protection applied to telegraph and telephone circuits—Glass tube fuse—Heat coils—Combined protector, heat coil, and fuse, fitting—Principles governing the fitting of heat coils and fuses—Heat coil and protector fittings—Precautions against fire—Test and cross-connection frame 574–586

CHAPTER XIX

EDEN MORNING TEST

General—Advantages—Method of demonstrating principle—Insulation resistance—Application of high resistances to the ends of the circuit—Resultant fault—Summary of results—Insulation resistance per mile—Fault at the centre of a circuit—Relations between "Sent," "Received" and "Perfect" currents and the resistance of a fault at the centre of a circuit of known resistance—Application of results obtained—Practical arrangement for Eden test—Verification of the E.M.F. of the testing battery—Interpretation of the results of the tests—Routine of the test—Eden test for position of a fault—Test for single wires—Localization tests with the tangent galvanometer—Effect of insulation resistance upon the speed of working 587–607

PAGE

CHAPTER XX

LOCALIZATION AND SPECIAL TESTING AND THE FORMATION OF SPECIAL CIRCUITS

PART I.—Localization tests :—

Organization—Various types of fault—Preliminary notes—Earths—Disconnections—Contacts—Intermittent faults—Covered wire faults—Test box detector—Causes which produce line faults 608–623

PART II.—The making good of faulty circuits, Special arrangements, and Earth currents :—

Symbols used for lines and apparatus upon plans—"Making good" of faulty circuits—The formation of special circuits—Earth currents 623–631

PART III.—The Wheatstone bridge and its uses :—

Wheatstone bridge—Principle—P.O. form—Practical use of bridge—Measurement of resistances having capacity, self-inductance, or an E.M.F.—Reversing switch and the measurement of the resistance of earthed circuits—Individual resistance of a number of circuits between the same two points—Periodical conductor resistance tests—Varley loop test—Murray loop test—Test for position of a contact—Pomeroy's method of testing earths 631–648

PART IV.—Insulation testing set and the Q and I detector :—

Insulation testing set—Electrification—The grouping of the wires in an air-space cable for insulation tests—Q and I detector 648 655

CHAPTER XXI

THE CONSTRUCTION OF AËRIAL LINES

Introductory—Timber—Preservative processes—Arms Insulators—Bronze wire—Choice of material for line wire—Iron wire—Copper wire—Binding-in—Joints—Earth-wiring—Dimensions of poles—Depth to which poles are buried—Stays—Splicing tool—Stay crutch—Pole spurs—Struts—A-poles—H-poles—Saddle wire—Pole-steps—Hook-guards—Iron poles—Erection of a pole—Use of derrick—Wiring—Sags and stresses—Stresses upon stays—Problems—Factor of safety of an open line—Renewals and alterations—Surveyings for open lines—Aërial cables—Interruption cables—Overhouse construction—Humming of wires—Silencing devices—Brackets—Standards 656–740

PAGE

CHAPTER XXII

THE CONSTRUCTION OF UNDERGROUND LINES

General—Conduits—Iron pipes—Duct routes—Slide pipes—Pillar test boxes—Flush boxes and pit channels—Manholes—Gutta-percha-covered wires—India-rubber-covered wires—Air space and paper core cables—Electrolytic action—Bonding pipes and cables—Inductive disturbances—Screened conductor cable—Air space cable—Twin type—Quadruple pair type—Composite cables—Multiple twin cables—Pulling in G.P. cables—Jointing G.P. wires—Renewal of G.P. cables—Numbering wires—Cable lengths—Pulling in lead-covered cables—Jointing lead-covered cables—Joint testing and dry air plant—Electrical tests during construction—Cable connection boxes—Cable distribution heads and solid joints—Single solid plugs—Double solid plugs—Renewal of G.P. with dry core cables—Renewal of dry core cables—Surveying—Faults—Pole test boxes—Junction of underground and open routes . . . 741-803

APPENDIX

A. The molecular theory of magnetism . . . 804–808
B. Notes on chemistry 809–814
C. Superimposing 815–825
D. The Murray automatic system 826–852
E. Quadruplex circuits, new standard arrangements . 853–857
F. Examples on the calculation of the capacity of circuits 858–861
G. Useful numbers 862–863
H. Standard wire gauge 864
I. Syllabuses of examinations 865–868

INDEX 689–912

TELEGRAPHY

INTRODUCTION

THE FUNDAMENTAL PRINCIPLES OF MAGNETISM AND ELECTRICITY AND UNITS.

STATIC ELECTRICITY.

ELECTRICITY pervades all space and all matter, but it is only when its distribution is altered that its presence is observed by the effects which result. One method of accomplishing this is by rubbing substances together, but the effect is due more to intimacy of contact between every portion of each surface rather than to actual friction. The result is that the two substances pass from the normal to the electrified condition. The condition of the two substances is different, and one is said to be positively and the other negatively electrified. The terms positive and negative are respectively used to imply a surplus above and a deficiency below the normal amount of electricity present.*

If a dry glass rod is rubbed with silk, it will be found that the glass is positively and the silk negatively electrified. A list may be prepared (from the results of experiments) in which substances are placed in such an order that upon any two substances named being rubbed together the resulting electrical condition of each may be stated according to their relative positions upon the list.

The electrified condition of a body may be imparted to

* Recent research shows that the negatively electrified body has the excess of electricity, and that, therefore, the true direction of a current is opposite to that in which it is at present assumed to pass.

others either by direct contact or by induction. Experiment proves that bodies similarly electrified, or charged, repel, and bodies oppositely charged attract each other.

It is vitally important to notice that in every case in which electrification results the values or quantities of positive and negative electrification are equal. This fact may be proved experimentally, or it may be deduced by mathematical analysis. If, therefore, a positive and a negative charge have been produced—suitable conditions being provided—an electric current will flow from the positively to the negatively electrified body until electrical equilibrium has been restored. Where these conditions have not been provided there always exists a force of attraction between the bodies.

Potential.

The term potential implies the power or capacity to do work.* Now a charged body is endowed with the power of attracting light substances—a property which an uncharged body does not possess. The uncharged body is said to be at zero potential, whilst the charged body has a positive or negative value according to the sign of its electrification. Potential corresponds very closely to level as applied to water, and just as a flow of water takes place from a higher to a lower level, so does a flow of electricity or an electric current take place from a higher to a lower potential in its endeavour to restore electrical equilibrium. The numerical value of potential is defined in terms of the work which a body can do in virtue of its potential. In order to correlate this definition with what has been said in regard to the identity of potential with electrical pressure, imagine a large tank filled with water and having a small pipe of considerable length leading from its base along the ground. Consider the difference in the rate at which the water

* This statement requires some qualification, since the power to do work obviously depends upon the potential of other bodies. No body can be said to have an *absolute* value of potential, since the conception essentially involves the *difference* in relative condition of two bodies or points. For simplicity, the earth is assumed to be at zero potential, and the potential of any particular body is given a definite value, but this is merely a method of briefly stating that a difference, equal to that value, exists between the potential of the body and the potential of the earth.

would leave the pipe according to whether the discharging end of the pipe was just below the level of the water, or whether the tank was raised high above the ground. The difference in level between the tank and the issuing water could clearly be defined in terms of the rate at which the water issued, or what is more to the point, in terms of the work which the issuing water, in virtue of its pressure, could perform.

Calculations in Electro-Statics.

The fundamental facts and definitions upon which the numerical aspects of the various effects are dealt with may be briefly stated as follows :—

1. *Force is anything which changes or which tends to change* (a) *the state of rest, or* (b) *the uniform motion of a body.*

2. *The unit of force (the dyne) is such that acting for one second upon a gramme of matter generates a velocity of* 1 *centimetre per second.*

If a gramme of matter is allowed to fall freely under the force of gravity, its velocity at the end of one second is in London approximately 981 centimetres per second. A force equal to the *weight* of one gramme is therefore 981 dynes.

3. *Work (in ergs) is equal to the force in dynes multiplied by the distance (in centimetres) through which it is overcome.*

4. *Unit quantity of electricity is such that when placed in air at a distance of one centimetre from a similar quantity it is repelled with unit force (one dyne).*

5. *Unit potential exists at any point when one erg of work is required to bring a unit of electricity of similar sign from an infinite distance up to that point in opposition to the force of repulsion.*

6. *The potential at any given point due to a charge is equal to the quantity of the charge divided by its distance from the given point.*

7. *The force of attraction or repulsion between two charges in air is equal to the product of their quantities divided by the square of the distance separating them.*

8. *The capacity of a conductor or system of conductors is equal to the quantity of the charge divided by the difference of potential existing.* (*Vide* page 14 also.)

MAGNETISM.

The starting point in magnetic research was the discovery of an ore to which pieces of iron and steel would adhere. This ore received the name of "lodestone" and is now known to be the black oxide of iron (Fe_3O_4). It was next discovered that a piece of steel, after being rubbed with lodestone, exhibited the same properties as the lodestone itself,—in fact, became what is now termed a permanent magnet.

The mariner's compass and the law governing attraction and repulsion between magnetic poles followed. The compass suggested that the earth itself is a magnet with its North and South poles approximately coincident with the North and South geographical poles. The actual position of the North magnetic pole is lat. 70° 5′ and long. 96° 46′ W., but it is believed that there are two South poles. A compass needle in London points about 16° west of the geographic North, but this value changes from year to year.

A piece of iron rubbed with lodestone exhibits little or no trace of magnetism when the magnet is removed. If, however, the lodestone is held in contact, the iron exhibits the properties of a magnet.*

Lines of Force.

The disturbance created in the region of a magnet is termed a magnetic field and its strength is determined by the value of the force of attraction or repulsion which it exerts upon magnets.

Lines of force are hypothetical lines along which an isolated magnetic pole would move if perfectly free to do so. Such a pole cannot, of course, be obtained and its existence is only postulated for the simplification of the reasoning. It may, however, be remarked that its use in dealing with the mathematical side of the subject is as frequent as it is valuable, and that the transition from the postulated pole to actual conditions is easily accomplished.

The directions of the lines proceeding from magnets are readily made apparent by sprinkling iron filings upon a

* The molecular heory of magnetism is given in Appendix A (*q. v.*).

sheet of paper or cardboard placed above the magnets. The lines of force in passing through the filings cause each one to become a magnet and to "line up" with its neighbours along the lines of force. It will, however, be noticed that the filings do not collect along the magnet itself, the reason being that iron and steel conduct lines of force far better than air and but few lines stray out of the metal into the surrounding air.

Every line of force is a closed curve, the direction of which is from South to North inside and North to South outside the magnet. Each line may be regarded as tending to repel the lines of force upon either side of it but having a tension along its length. Again, lines of force can never cross each other. Where such a tendency exists the lines repel each other and form separate and distinct curves. Every line of force tends to shorten itself, and where motion of a system is possible, that motion takes place in such a way as to render the lines as short as possible.

Magnetic Induction.

The difference between a magnet and a piece of non-magnetic material is, that the magnet possesses lines of force, whereas the non-magnetic material does not; also, that in the latter case, lines passing through it do not render it magnetic since its molecules are not magnets. If lines pass from right to left through a bar of iron, at the right-hand side of the iron there will be a South, and at the left-hand side a North pole. The statement is identical with that contained in the subsequent paragraph, and if the reader will draw a couple of bars in a straight line with each other—one representing a magnet and the other a piece of iron—he will, by filling in the directions of the lines of force due to the magnet, observe the direction in which they pass through the iron bar, and thus deduce the induced polarity of that iron bar.

Induction takes place along the lines of force, and *the induced pole is opposite in character to the inducing pole;* or, to give an example, a North pole approached to the right-hand side of an iron bar causes that end to become a South pole, the result being attraction. The attraction between a magnet and a piece of iron is, therefore, the

result of previous induction. A line of force passes just as easily through brass, wood, glass, etc., as through air; hence the interposition of a piece of copper or other non-magnetic substance does not affect the action of the magnet. From that which has been already said on the subject of lines of magnetic force, it will be seen that the molecules of a magnetic substance arrange themselves along the lines, and that to magnetize a piece of steel the magnet should be stroked along in one direction only. The end at which the stroke ceases will be opposite in polarity to the pole with which the steel is rubbed.

Quantitative Values of Magnetic Effects.

The various calculations in regard to magnets are based primarily upon the definition of a unit magnetic pole, and for the use of more advanced students a few of the more important definitions and experimental facts are succinctly given below.

1. *A unit magnetic pole is such that when placed, in air, at a distance of one centimetre from a similar pole it is repelled with unit force (one dyne).*

2. *A magnetic field of unit intensity has one line of force per square centimetre passing through it; it acts on unit pole with unit force.*

From definition 2 it follows that unit magnetic field exists at every point one centimetre from a unit magnetic pole of indefinitely minute size. In other words, 4π lines of force proceed from a unit magnetic pole and one of these lines passes through each square centimetre of the area of an imaginary sphere described, with a radius of one centimetre, around the unit pole.

3. *The force of attraction or repulsion (in dynes) between two magnetic poles is equal to the product of their strengths divided by the square of the distance separating them.*

As an example of the way in which these definitions may be employed, imagine that a magnet having a pole strength of 10 units and length 8 centimetres is placed with its nearer pole 5 centimetres from a magnetic pole of 3 units strength.

Force due to nearer pole $= \frac{10 \times 3}{5^2}$ dynes.

Force due to more distant pole $= \frac{10 \times 3}{13^2}$ dynes.

Net effect on isolated pole $= \frac{10 \times 3}{5^2} - \frac{10 \times 3}{13^2}$ dynes.

$= 1{\cdot}02$ dynes approx.

The *moment* of a magnet is defined as the product of its pole strength and its length. A rough approximation to the result given above is contained in the statement that the force due to a magnet at a given point, in a straight line with it, is directly proportional to its moment and inversely proportional to the cube of the distance of the centre of the magnet from the given point.

VOLTAIC ELECTRICITY.

The arrangement termed a voltaic cell consists essentially of two dissimilar metals immersed in a liquid which will form a chemical compound with one of them, *e.g.* a piece of copper and a piece of zinc immersed in dilute sulphuric acid. For the present this primitive form of cell will serve the purpose of illustrating one method of producing the effect known as an electric current. The term "battery" will be used to describe a collection of cells properly connected together.

A copper wire joining the zinc and copper ends of a voltaic cell has properties which are not possessed by an ordinary piece of copper. These properties, which arise from the fact that the wire conveys an electric current,* are thermal and magnetic. If a cell of sufficient dimensions is employed in conjunction with a thin wire the latter may be made incandescent. In every case heat *is* generated, but frequently the amount is too small to be measured or observed by any ordinary method. The magnetic effect is, however, far more readily shown.

* The discussion as to what electricity may actually be is far beyond the scope of this work, but a reference to the source from which the trend of modern thought may be gathered will probably be useful to some readers. The reference is *Journal of the Institution of Electrical Engineers*, Vol. XXXII, "Electrons," by Sir Oliver J. Lodge.

A magnetic field exists round any wire carrying an electric current, and the lines of force will be found to lie in concentric circles with the wire as centre. This fact can be demonstrated by a current-conveying wire passing through a piece of glass or cardboard upon which iron filings are strewn. The general appearance of the filings, after tapping the glass or cardboard so as to enable the filings to settle into position, is indicated in Fig. 1.

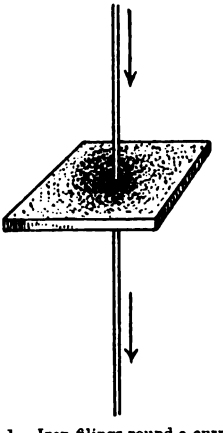

FIG. 1.—Iron filings round a current-conveying wire.

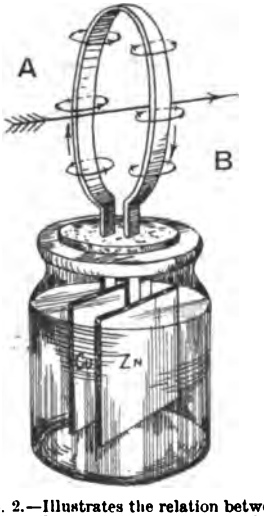

FIG. 2.—Illustrates the relation between the direction of a current and its magnetic field.

An electric current has magnitude and direction. Its direction outside the cell is from the copper pole through the wire to the zinc pole, and the magnetic field created is always in strict accordance with the magnitude and direction of the current.

A few of the lines of force generated in a conductor bent into a loop are shown in Fig. 2, in such a manner that the relation between the direction of the current and the direction of the magnetic field produced is at once apparent.

A compass needle or a freely suspended magnet points

to the magnetic North and South, and force is required to deflect it from that position. The best position in which the force can be applied so as to produce the maximum deflection is at right angles to the needle. A magnet, placed at right angles to the needle, *tends* to send lines of force straight across it, thus attracting one pole and repelling the other. If the earth's field were absent the compass needle would set itself along the magnet's lines of force, in precisely the same way that the compass needle normally sets itself along the earth's lines of force. When both fields are present the needle is urged by two forces at right angles to each other, and the position which it takes up depends entirely upon their relative magnitudes. If equal, then a deflection of 45° results.

It has already been pointed out, that, round a wire conveying a current, there are lines of force arranged in concentric circles at right angles to its length. Also that the difference between an ordinary piece of wire and one conveying a current is the absence of the magnetic field in the former case. If the current-conveying wire is placed in such a position that its magnetic field acts at right angles to that due to the earth, an alteration in the position of a compass needle placed at that point will result. The position in which the wire should be placed so as to produce the effect described is above or below, but in the same straight line as the needle. The wire's lines of force pass round the wire in planes at right angles to the length of the wire, thus *tending* to cut the earth's lines of force at right angles, and so produce a deflection of the needle.

It has been stated that where two magnetic fields whose directions when separately considered were at right angles to each other, the magnetic fields *tended* to cross one another. Lines of force can never cross each other, because the magnetic field at the point of intersection would, in that case, have two values, which is manifestly impossible. A current-conveying wire lying in the magnetic meridian directly above a compass needle causes the needle to be deflected. The field due to the earth is altered in its distribution by the field due to the current, and the needle sets itself in the direction in which the re-distributed lines now stand. In other words, a resultant magnetic field is produced by the action of the two separate fields and its

direction and magnitude depend upon the values of the two fields.

By reversing the battery connected to the wire the direction of the lines of force due to the current is changed.

The direction of a line of force above a current-conveying wire is opposite to its direction below the wire (see Fig. 2), and therefore the direction in which a compass needle is deflected is dependent not only upon the direction of the current, but upon whether the wire is held above or below the needle. There are many rules for memorizing these effects, but three only will be given.

1. Mnemonic "**SNOW**," a current passing from **S**outh to **N**orth **O**ver the needle causes the North pole to be deflected to the **W**est.

2. Place the outstretched *right* hand between the wire and the needle, with the palm of the hand facing the needle, so that were the hand the wire, the current would flow from wrist to fingers. The outstretched thumb will then indicate the direction in which the North pole will turn.

3. Imagine a man swimming in the wire in the direction of the current, and that he turns so as to face the needle, then the North pole of the needle will be deflected towards his left hand.

The converse of these rules, *i. e.* the determination of the direction of a current from the known direction in which a compass needle is deflected, is sufficiently obvious.

Conductors and Insulators.

If the poles of a voltaic cell are joined by a dry piece of glass it will be found that no current exists. It is therefore clear that glass is a substance that will not permit the effect termed an electric current to take place along it. Such substances are termed non-conductors, or insulators, in contradistinction to conductors, and of all known substances silver conducts electricity most freely, whilst perfectly dry air is the best insulator. Electrical conductivity is, however, a matter of degree, for, whilst no substance conducts perfectly, it is certain that no substance is a perfect insulator. The best conductors are metals in the following order :—Silver, copper, gold, zinc, platinum, iron, tin, lead, and mercury. Next come carbon, acids, salt

solutions, and water. Taking insulators in the same way the order is :—Dry air, glass, ebonite, paraffin wax, india-rubber, gutta-percha, silk, wool, porcelain, oils, paper, marble. This order is, however, subject to variations in accordance with the condition of the material.

The path, along which a current flows, is termed a circuit, and it is said to be completed when the current is passing.

UNITS.

Before electric currents can be compared standards must be defined in just the same way that the units of length, weight, and time, are defined in ordinary commerce.

Electromotive force stands in much the same relation to electricity as pressure does when applied to water. The different degrees to which various substances will permit the passage of a current has already been remarked. Another way of expressing the same fact is to say that some conductors offer more *resistance* than others.

A pipe of fixed size will deliver water at a certain rate when a given pressure is applied. An increase in the pressure or an increase in the size of the pipe will result in a corresponding increase in the flow of water through it. Similarly in an electrical circuit an increase in the electrical pressure or E.M.F., or a reduction in the resistance of the circuit will result in an increased value of *current*.

The units of current, electromotive force and resistance are as follows :—

Current	The ampere.
Electromotive force . .	„ volt.
Resistance	„ ohm.

THE OHM is represented by *the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice* (0° *C. or* 32° *F.*) 14·4521 *grammes in mass, of a constant cross sectional area, and of a length of* 106·3 *centimetres.*

This unit represents about the resistance offered by $80\frac{1}{3}$ yards of the gutta-percha covered wire formerly used in joining up the instruments upon the tables in a telegraph office. It is the resistance offered by about 200 yards of 100 lb.

copper line wire, or by about 132 yards of 400 lb. iron line wire.

THE VOLT is represented by ·6974 ($\frac{1000}{1434}$) *of the electrical pressure at a temperature of* 15° *C. between the poles of the voltaic cell, known as Clark's cell,* set up in accordance with a detailed specification.

The E.M.F. of a Daniell cell is rather more than one volt, whilst that of the Clark cell is rather less than $1\frac{1}{2}$ volts (actually 1·434 volts at 15° C.).

THE AMPERE is *the current which will flow through a circuit having a resistance of one ohm when urged by an electromotive force of one volt.*

Such a current will deposit silver from a solution of nitrate of silver in water at the rate of ·001118 of a gramme per second. This is the legal definition of a current of one ampere, and a specification is appended stating the details of the method of carrying out the determination.*

In telegraph practice the ampere is too large a unit, and it is therefore sub-divided into "milli-amperes," which, as the name implies, means thousandth parts of one ampere. This is usually denoted by the contraction "m.a.," and 1000 m.a. would therefore mean one thousand milli-amperes, or one ampere.

In order to avoid the constant writing of the words "ohm" or "ohms" after numbers the small Greek letter "ω" (omega) is used as an affix. Thus, "one hundred and fifty ohms" is written "150ω." The capital letter has been similarly employed to represent "megohms" or millions of ohms, thus 10^{Ω} means 10 megohms or 10,000,000ω. This convention is extremely useful in stating insulation resistances, which are usually of this order of magnitude.

For extremely small resistances such as the resistance between the opposite faces of a unit cube of metal or other highly conductive substances the "microhm" or one millionth of an ohm is very frequently employed. For instance, the expression "165 microhms" therefore represents ·000165ω.

* The definitions of the three units, together with the specifications as to determination, are to be found in the *Electrician* of August 31, 1894, page 518.

OHM'S LAW.

Ohm discovered that the following relations existed between these units : *The strength of current through any circuit varies directly as the electromotive force and inversely as the resistance*, or, stated in a more definite manner, the number of amperes flowing through a circuit is equal to the number of volts of electromotive force divided by the number of ohms of resistance in the entire circuit, or :—

$$\text{Current} = \frac{\text{Electromotive force}}{\text{Resistance}} \quad i.e.\ C = \frac{E}{R},$$

whence $$R = \frac{E}{C}, \text{ and } E = C \times R,$$

where C, R, and E, are respectively the current, resistance, and electromotive force in the circuit.

For instance, an E.M.F. of 12 volts applied to a circuit of 6 ohms resistance will produce a current of $\frac{12}{6} = 2$ amperes. If the E.M.F. in a circuit be 30 volts and the current 10 milli-amperes, its resistance must be $\frac{30}{.010} = 3000$ ohms. If the current is 2 amperes and the resistance is 10 ohms, then the E.M.F. in the circuit will be $10 \times 2 = 20$ volts. These quantities should *all* be expressed in volts, amperes, and ohms.

B.A. AND STANDARD UNITS.

Here it may be well to carefully define the difference between B.A. units and Standard units. The value of the ohm is stated in reference to the fundamental units of length and time, *i.e.* in reference to centimetres and seconds. This value is determined by absolute measurements, and when the value was given by the British Association it represented the most careful and exact determination which could at that time be made. Later, with ever increasing knowledge and more accurate experiments, it became evident that the former results were incorrect to the extent of rather more than one per cent. Accordingly new determinations were undertaken with the result that the value of the ohm was defined as given above.

The unit of current was left unchanged, and to accomplish

this a revision of the value of the volt was necessary. The B.A. ohm was multiplied by 1·0136 and therefore the volt had similarly to be multiplied in order to keep the value of the current the same. This gives "standard" ohms and volts as laid down by the Board of Trade.

It should be remarked, however, that although several years have passed since this change was made there is still much apparatus in use where the values are marked in the old units. Every accurate measuring instrument in use by the Department is marked "Standard ohms" where the revision in value has been made.

OTHER ELECTRICAL UNITS.

From the three units of current, E.M.F., and resistance, the remaining electrical units may readily be derived and, although detailed treatment is scarcely possible in a work of this description, it is undesirable to entirely omit them since there are many cases in which their use is essential.

THE COULOMB *is the unit of quantity of electricity and may be defined as the quantity of electricity which would pass any given point in a circuit carrying an unvarying current of one ampere in one second.*

THE FARAD *is the unit of capacity and represents the capacity of a condenser which at a pressure of one volt would be charged with one coulomb of electricity.*

Relationships analagous to Ohm's law exist between E.M.F., quantity, and capacity. They are :—

$$\text{Difference of potential} = \frac{\text{Quantity}}{\text{Capacity}}$$

$$\text{Capacity} = \frac{\text{Quantity}}{\text{Difference of potential}}$$

$$\text{Quantity} = \text{Difference of potential} \times \text{capacity}.$$

If a condenser of ·001 farad capacity has a charge of ·2 coulombs the difference of potential across its terminals is $\frac{2}{\cdot 001} = 200$ volts.

As an example of the second relation suppose that the quantity of electricity in a condenser is ·01 coulomb whilst

the difference of potential across its terminals is 50 volts. The capacity is then $\frac{0 1}{5 0}$ = ·0002 farad.

The third form of the relation is illustrated by ascertaining the charge in a condenser of say ·00002 farads capacity due to the application of an E.M.F. of 50 volts. It is 50 × ·00002 = ·001 coulomb.

The values of the capacity chosen in these examples have been extremely small fractions of the unit, the farad, but even these fractions are far larger than are met with in the case of long aërial or even short underground telegraph circuits, consequently a sub-division of the farad, the microfarad, is employed in practice. It is equal to one millionth part of one farad and is usually denoted by the affix "m.f."

An example of a case occurring in telegraph practice is that of a shunted condenser (*q. v.*). If an E.M.F of 30 volts is applied to a condenser of $3\frac{1}{2}$ m.f. capacity the value of the charge will be $\frac{30 \times 3\frac{1}{2}}{1{,}000{,}000}$ = ·000105 coulomb.

One microfarad is the capacity of about three miles of a telegraph circuit consisting of a gutta-percha covered wire laid in pipes in the earth. It is the average capacity of about 70 miles of 100 lb. copper wire erected upon poles and of 8 miles of 40 lb. conductor screened cable laid underground.

The unit of self-induction still remains to be considered. The phenomenon is simple and capable of easy explanation, but the complete definition of the value of the self-inductance of a circuit is somewhat complex.

Wherever a current exists there is a magnetic field. This field is the result of the current, and in coming into existence it cuts through the current-conveying conductors to which it owes its origin. Now wherever a magnetic field cuts a conductor or *vice versa* an E.M.F. is generated. Imagine a battery or other source of E.M.F. applied to a coil of wire such as that shown in Fig. 27. The current does not instantly attain its full value, since its rise is opposed by the E.M.F. generated by the lines of force cutting through the conductors. This opposing E.M.F. is termed the "back E.M.F." of self-induction. If, now, the coil and battery are short-circuited, a current will flow through the circuit in the same direction as the original

battery current. This is caused by the collapse of the lines of force which, in so doing, cut through the conductors in the opposite direction.

THE HENRY is the unit of self-inductance, and represents *the self-inductance of a circuit in which a counter E.M.F. of one volt is generated when the value of the current changes at the rate of one ampere per second.*

One or two general remarks may be made upon this definition, but detailed treatment is altogether beyond the scope of the present work.

If a bar-magnet is plunged into a coil of wire its lines of force cut through the conductors and an E.M.F. is generated. The value of this E.M.F. depends directly upon the strength of the magnetic field, the rate of motion, and upon the number of convolutions of wire. In any given coil the E.M.F. will be directly proportional to the strength of the magnetic field encircling the convolutions, hence doubling the field means doubling the E.M.F. generated. This E.M.F. will also be directly proportional to the number of turns of wire. If, therefore, the number of turns of wire in the coil be doubled the generated E.M.F. will similarly be doubled. From these two statements it may be deduced that the self-inductance of a coil of wire is directly proportional to the *square* of the number of turns of wire. If a current through one turn of wire is suddenly started or stopped an E.M.F. proportional to the magnetic field created or destroyed is generated. If the same current is still employed, but two turns of wire are included, it will be obvious that the magnetic field will have been doubled. This doubled field cuts twice as many turns of wire, hence the E.M.F. generated in the case of two turns is 2^2 or four times that of one turn. Similarly 5 turns would mean 5^2 times the E.M.F. generated, or from the above definition would mean 25 times the self-inductance.

The self-inductance of an electromagnet varies with the value of the current employed, being largest for small values. Hence in stating the self-inductance of a relay, for instance, the value of the current is stated. The self-inductance of a P.O. standard "A" relay is 3·25 henries, "B" relay 2·14 henries, "C" relay 26·4 henries, and of a Siemens relay 7·07 henries respectively for a current

of 20 m.a. The self-inductance when small in value is often expressed in thousandths of a henry or in millihenries.

The self-inductance of a relay with its coils in parallel is one-quarter of its value with its coils in series, since the effective number of turns is one-half in the latter case.

The units of power and energy may be given to complete the list of practical units. *The watt is the rate at which work is done when one ampere flows through a conductor with a difference of potential of one volt across the ends of the conductor.*

$$\text{Watts} = E \times C \text{ or } C^2 \times R \text{ or } \frac{E^2}{R}.$$

An incandescent lamp requiring ·56 ampere upon a 100 volt circuit therefore takes $100 \times \cdot 56 = 56$ watts. As 746 watts is equal to one horse-power the lamp is taking approximately $\frac{3}{40}$ of one horse-power.

The commercial unit in which electrical energy is sold by electrical undertakings is known as the Board of Trade unit and is the practical unit of energy. *The Board of Trade unit is equal to* 1000 *watt hours*, i.e. 1·34 *horse-power for one hour.*

Twenty of the lamps mentioned above would consume 1120 watts, and if burning for three hours the energy used would be $1120 \times 3 = 3360$ watt-hours or 3·36 B.O.T. units.

CHAPTER I

PRIMARY CELLS.

AN electric current represents a certain amount of energy. It is not in the power of man to *create* energy, but the energy with which the world is endowed may be applied to effect desired ends. A voltaic cell may be defined as a piece of apparatus which converts chemical energy into electrical energy. A due appreciation of this will greatly facilitate the comprehension of the processes involved in the voltaic cell. A cell supplies electrical energy, in the shape of an electric current, by taking an amount of chemical energy, equal to the electrical energy, from the constituent parts of the cell.

In the simple cell previously mentioned the sulphuric acid attacks the zinc, and with it forms a chemical compound known as sulphate of zinc. If, however, a cell of this description is put to practical uses, it will be found that the current grows rapidly weaker, until at last it almost ceases. The reason is that the hydrogen, which is liberated in the re-arrangement of the chemical compounds, forms a layer of gas over the copper plate. Again, the impurities in the zinc, such as iron, tin, arsenic, etc., combine with the zinc to form little batteries, and waste it away without any equivalent of work done in the external circuit. This evil is known as *local action*. The words "external circuit" are used in contradistinction to the "internal circuit," or path of the current inside the cell itself. The troubles to which the impurities in the zinc give rise are eliminated by the process known as *amalgamation*, which consists in coating the zinc with mercury, thus making it behave as though it were chemically pure.

Although this remedy has been known since 1828 the

theory of its action is still undecided. It has been suggested that, since zinc amalgamates so readily, the zinc at once passes to the surface of the amalgam, whereas the impurities, being less readily amalgamated, do not pass to the surface. The amalgam would thus act as a filter, but as soon as it became thin the impurities would project and local action result, which is found to be the case.

This view of the matter is satisfactory so far as the impurities are concerned, but it fails to explain the absence of local action between the zinc and the mercury.*

The accumulation of the hydrogen upon the negative element is not so easily remedied. The thin coating of this electro-positive gas gives rise to what is termed "polarization" and its effects are most deleterious.

Firstly, covering the surface of the plate with hydrogen reduces the area in contact with the liquid which increases the internal resistance of the cell (see Chapter II). Secondly, and this is by far the more serious aspect of the question, hydrogen is electropositive, and therefore tends to recombine with the zinc sulphate and so to deposit zinc upon the negative element. The statement of this tendency is another way of saying that an E.M.F. is set up in opposition to the prime E.M.F. of the cell. The E.M.F. of the cell under such conditions is seriously decreased. In a simple cell such as that considered it was found that the E.M.F. fell from ·85 volt to ·54 volt in one minute after its terminals were joined through a resistance of 10^{ω} and to ·355 volt at the end of five minutes. It will therefore be realized how serious a matter polarization becomes, and that its prevention is imperative if anything which even remotely resembles a steady current is to be obtained.

The E.M.F. of any particular type of cell is independent of its dimensions, but its internal resistance is dependent upon them, and generally speaking the larger the cell the lower is its internal resistance, and also the greater is the amount of electrical energy which may be obtained for a single charge. These points are, however, reverted to in Chapter II.†

Although it has been noted that the hydrogen liberated

* *Primary Batteries*, by W. R. Cooper.

† At this point readers who have little or no knowledge of chemistry are advised to carefully read Appendix B on chemistry.

during the action of the cell is deposited upon the negative element, the way in which this occurs has not yet been dealt with. The hydrogen does not pass from the positive element through the electrolyte in the form of bubbles. Upon being liberated by the combination of zinc with the sulphuric acid it immediately combines with the SO_4 of an adjacent molecule of H_2SO_4, thus liberating the hydrogen from this molecule. The action is repeated across the liquid until the negative element is reached, when the hydrogen comes off in the form of visible bubbles. No sign of the action is to be seen in the liquid which intervenes between the two elements of the cell.

It has already been stated that zinc is the negative and copper the positive terminal of the cell under consideration. In the external circuit the current flows from copper to zinc, but in order that the circuit may be complete (without which there can be no current) the current must flow from zinc to copper *inside* the cell, hence to express both facts the *zinc* is termed the *positive element*, but the *negative pole* or terminal of the cell. Similarly the *copper* is the *negative element* but the *positive pole*.

The positive metal or element is always the one which is acted on or consumed by the liquid. The liquid which consumes the zinc, when the circuit is completed, is called the *exciting fluid*, as opposed to the liquid taking up the hydrogen which is called the *depolarizing fluid*. The hydrogen causes polarization unless means are employed to get rid of it, or in other words to *de*polarize the cell.

Daniell Battery.

The Post Office form of Daniell battery consists of a teak trough with a hinged lid and divided by slate partitions for the required number of cells. In the five-cell form (Fig. 3) the trough is divided into five compartments or cells by means of four slate partitions. The whole of the interior of the trough is treated with marine glue, which affords an adhesive surface for the glass plates that line the four sides and the bottom of each cell, thus rendering them perfectly watertight. A small projection is raised near the centre of each cell for the purpose of keeping in position the jar of unglazed earthenware usually termed a

" porous pot." This porous pot is slightly wedge-shaped in section, having its smaller end for base, and is laterally very wide, but is short in the direction of the length of the battery. The porous pot is usually treated with paraffin wax save upon the side which faces the zinc plate furthest away from the slate partition. This slightly increases the internal resistance, but very considerably arrests the intermingling of the solutions. The copper plate in the large size of cell measures $4\frac{1}{2}$ inches by $4\frac{1}{2}$ inches, and is contained in the porous pot which is filled about three parts full of copper sulphate crystals (about four ounces) and filled up with water. This gives a saturated solution of copper sul-

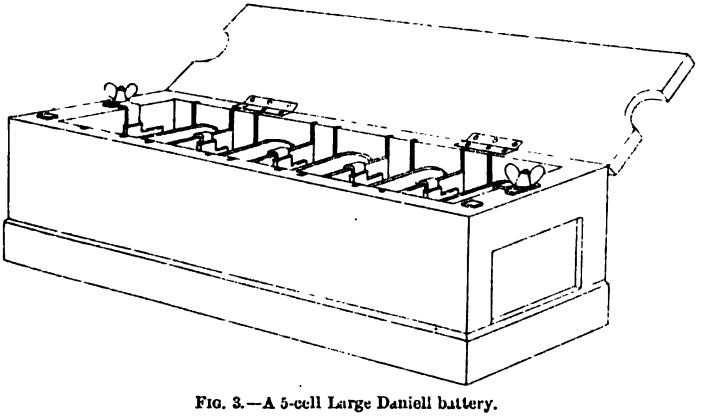

FIG. 3.—A 5-cell Large Daniell battery.

phate, the strength of which is constantly maintained since fresh crystals dissolve as fast as the copper sulphate solution is weakened by the action of the cell. The remaining space in the compartment is occupied by a zinc plate $4\frac{1}{2}$ inches by $2\frac{1}{2}$ inches in area, together with the exciting fluid which consists of soft water, or under special circumstances, of a sulphate of zinc solution.

The five-cell battery is furnished with four pairs of plates and two end plates. A thin copper strap is cast into each of the four zinc plates and a rivet is employed to make the connection to the copper plate of the subsequent cell. The copper plate is placed in one cell and the zinc end of the

pair of plates in the next cell, and the battery is therefore internally joined up without the aid of binding screws. The last plate at each end is separate, and these end plates are connected to the two binding screws which form the terminals of the battery.

It has been previously pointed out that the hydrogen which is liberated during the action of a cell gives rise to the trouble known as polarization. The copper sulphate solution has for its object the continuous absorption of the hydrogen as fast as it is formed. The porous pot prevents the exciting and depolarizing fluids from freely intermingling, but at the same time keeps them in intimate electrical contact, thus enabling a current to flow from one to the other.

Chemical Action.—When the poles of the cell or battery are joined by a wire, the oxygen of the water attacks the zinc, forming an oxide of zinc and liberating hydrogen, which, upon reaching the copper sulphate solution, combines with it, thus forming sulphuric acid and metallic copper, the latter being deposited upon the copper plate. The sulphuric acid sooner or later finds its way into the outer part of the cell, where it attacks the zinc, when the chemical action previously shown in the case of the simple cell results. It will be noticed that where the exciting fluid consists of dilute sulphuric acid, the action of the depolarizer is to form sulphuric acid in the porous pot just as fast as it is neutralized in the zinc part of the cell. The strength of the acid solution is therefore kept up, and in practice it is necessary to occasionally remove the solution in the zinc compartment, and replace it by water.*

Leaving the first action resulting in the formation of

* The chemical action of a Daniell cell in which water only is present in the outer compartment, is

$$Zn + H_2O = ZnO + H_2$$
$$H_2 + CuSO_4 = H_2SO_4 + Cu$$

With a zinc sulphate solution

$$Zn + ZnSO_4 = ZnSO_4 + Zn$$
$$Zn + CuSO_4 = ZnSO_4 + Cu$$

It is interesting to note that in this case zinc, and not hydrogen, is the polarizing ion.

zinc oxide, sulphuric acid and metallic copper, we may consider the action in the outer cell identical with that of the simple cell previously quoted, viz. :—

$$Zn + H_2SO_4 = ZnSO_4 + H_2$$

These two atoms of hydrogen upon reaching the copper sulphate solution unite with it thus :—

H_2	+	$Cu\,SO_4$	=	H_2SO_4	+	Cu
Two atoms of hydrogen	and	one molecule of copper sulphate	form	one molecule of hydrogen sulphate	and	one molecule of copper.

Hydrogen sulphate is merely another name for sulphuric acid, and it has been employed merely to render the changes in the distribution of the chemical compounds more obvious to the non-chemical reader.

Practical Notes.—In setting up a battery, a considerable time has to be allowed for the solutions to permeate the porous pot, and force out all the air left in the pores. This process is greatly shortened by charging the porous cell, and then allowing it to stand alone for a short time before adding the water to the zinc compartment. A battery properly made up should be ready for actual use in about 24 hours. The addition of a little zinc sulphate to the water considerably improves its conductance, and this course is recommended where the battery is required for immediate use. Here it may be well to point out that, under no circumstances must dilute sulphuric acid be used instead of water—the objection being that the amount of local action is thereby very greatly increased.

A given quantity of water will only hold a certain definite quantity of zinc sulphate in solution, and when the limit is reached the zinc sulphate begins to crystallize out, and deposits itself upon the zinc plate. It will therefore be seen that the solution should be replaced by water whenever there is the slightest indication of the point of saturation being approached.

The presence of copper sulphate in the zinc compartment leads to the deposition of copper in the form of black mud upon the zinc plate. When this happens, the plate should of course be removed and cleaned before being

replaced in the water which has been substituted for the solution.

Two sizes of Daniell battery are used by the Department, designated "Large" and "Small." In the latter type the copper plate measures $3\frac{1}{4}$ inches by $3\frac{1}{4}$ inches, against the $4\frac{1}{2}$ inches by $4\frac{1}{2}$ inches of the "Large" type. In future no more "Small Daniell" batteries will be manufactured, and as each battery becomes useless, its place will be taken by the Large size. It will, however, be some con-

FIG. 4.—Porous pot form of Leclanché cell.

FIG. 4A.—Agglomerate form of Leclanché cell.

siderable time before the last "Small Daniell" has been scrapped.

LECLANCHÉ CELLS.

The containing vessel of this cell (Fig. 4) consists of a square glass jar, ending in an almost circular collar, shaped to admit the zinc rod which forms the positive element. The rod is cast on to a copper wire, which is insulated where it emerges from the zinc and forms one terminal of the cell. The collar and a portion of the jar itself is usually very heavily coated with a special paint to arrest the creeping of the salt. Inside the jar is placed a circular porous pot

containing the negative element, a carbon plate, and the depolarizer, manganese dioxide, commonly termed pebble manganese. The manganese should be free from dust, as this is found to exercise a most deleterious effect upon the working of the cell.

The top of the carbon plate is capped with a heavy lead lug carrying a brass terminal. In order to arrest injurious affection of the lead lug and its terminal, the lug and a

FIG. 5.—Post Office form of Leclanché cell, with the shallow circular zinc and earthenware jar.

small part of the upper portion of the plate are thickly coated with paint. The top of the porous pot is sealed over with the carbon plate in position, two small vents being left for the escape of any gases generated.

The exciting fluid is a solution of salammoniac (ammonium chloride) contained in the outer jar. It is essential that both the porous pot and its contents shall be wet, in order to permit the passage of the current through the cell. Therefore a certain amount of water or

a weak salammoniac solution is added to the porous pot. The latter is a much better conductor than the former.

In order to avoid the necessity of a porous pot, the depolarizer is often made in the form of slabs, carbon and gum lac resin being added for the purpose. Such a cell, known as an agglomerate Leclanché, is shown in Fig. 4A. The advantages gained are, firstly, a notable decrease in the internal resistance of the cell; secondly, the depolarizing power of the manganese is utilized to a much greater extent; and thirdly, that the cell is ready for use immediately after being charged. There is, however, the slight disadvantage that a small decrease in the E.M.F. of the cell

FIG. 6.—Shallow circular zinc.

occurs, due probably to the use of a different form of manganese.

These cells, of both the porous pot and agglomerate pattern, are usually made in three sizes, known as No. 1, No. 2, and No. 3 sizes. The sizes employed by the Department are Nos. 1 and 3, *i. e.* the three-pint and one-pint sizes respectively. In the case of the latter, terminals are dispensed with, as in the Daniell, by making the connection carbon to zinc a permanent one.

A large circular zinc plate surrounding the porous pot was formerly employed with the No. 1 size, but this has now given place to the shallow circular zinc illustrated in Fig. 6. The large zinc plate was found to be very wasteful, as the current is not equally distributed throughout the

area of the zinc, the result being that it is worn away very unevenly. A hole occurs about an inch and a half from the bottom, and also at the top of the liquid. By experiment it was found that the zinc could be reduced to the form mentioned without any undue increase in the resistance of the cell.

Yet another form of cell in use by the Department, chiefly for telephone working, is the six-block agglomerate form. It consists of a thick carbon rod grooved to receive six cylindrical agglomerate blocks. These blocks are placed in position, a coarse canvas cloth wrapped round the combination, and the whole held together by means of two india-rubber bands. The zinc is of the shallow circular pattern, and is contained in an earthenware jar. The complete cell is depicted in Fig. 7.

Fig. 7.—6-block Leclanché Agglomerate cell.

The cells are enclosed in suitable boxes holding a convenient number of cells.

Chemical Action.—When the cell is thus made up there will be no action whatever, as the salammoniac will not attack the zinc, in fact will not have the slightest effect on it when the circuit is not closed. When the circuit is closed, the chemical compounds are entirely altered in their distribution. Salammoniac is a compound of ammonium and chlorine, and is represented by NH_4Cl (one atom each of nitrogen and chlorine, together with four atoms of hydrogen). When the circuit is closed, the zinc and the ammonium in the salammoniac change places, and thus part of the zinc will be consumed to form zinc chloride (a substance that readily dissolves in the salammoniac solu-

tion), ammonia (which, however, immediately combines with water to form ammonium hydrate) and hydrogen which is set free. This hydrogen, which appears at the carbon plate, must be removed in order that it may not give rise to the troubles described in the case of the Daniell cell. The depolarizer used in the Leclanché cell is, as previously stated, the manganese dioxide packed round the carbon plate. Immediately the hydrogen is liberated it combines with the oxygen of the manganese to form water. The action may be stated thus :—

Outer cell :—

$$\underset{\text{One molecule of zinc}}{Zn} + \underset{\text{together with}}{} \underset{\text{two molecules of salammoniac}}{2NH_4Cl} + \underset{\text{and}}{} \underset{\text{two molecules of water}}{2H_2O}$$

$$= \underset{\text{form}}{} \underset{\text{one molecule of zinc chloride}}{ZnCl_2} + \underset{\text{together with}}{} \underset{\text{two molecules of ammonium hydrate}}{2NH_4HO} + \underset{\text{and}}{} \underset{\text{two atoms of hydrogen.}}{H_2}$$

Inner Cell :—

$$\underset{\text{Two atoms of hydrogen}}{H_2} + \underset{\text{and}}{} \underset{\text{two molecules of manganese dioxide}}{2MnO_2} = \underset{\text{form}}{} \underset{\text{one molecule of manganese sesquioxide}}{Mn_2O_3} + \underset{\text{and}}{} \underset{\text{one molecule of water.}}{H_2O}$$

In the inner cell it will be seen that the two molecules of manganese dioxide taking part in the reaction have between them given up one atom of oxygen to the hydrogen, thus forming water. On the other hand, the two molecules of manganese dioxide has become one molecule of a lower oxide, namely, Mn_2O_3, the sesquioxide of manganese.

Fuller's Mercury Bichromate.

This cell (Fig. 8) consists of an outer earthenware jar containing the carbon plate and the porous pot. The latter contains a thick zinc rod specially amalgamated, the base of which is flattened to form a sort of pedestal. The porous pot is filled up with very dilute sulphuric acid and the outer jar with a mixture of sulphuric and chromic acids. Chromic acid is somewhat dear, whereas both bichromate of potash and sulphuric acid are cheap, and as chromic acid is formed when these two substances are brought together, it is cheaper to charge the cell with bichromate of potash

and sulphuric acid. This, however, results in the formation of a bye-product, but fortunately a harmless one.

Two ounces of mercury are placed in each porous pot for the purpose of keeping the zinc perpetually amalgamated. This device, from which the cell derives the adjectival part of its name, is remarkably efficient and reduces the amount of local action to a minimum.

FIG. 8.—Bichromate cell.

Chemical Action.—The action of the dilute sulphuric acid on the zinc results in the formation of zinc sulphate which dissolves in the solution, and the liberation of hydrogen which makes its appearance at the carbon plate where the chromic and sulphuric acids combine with it to form water and chromium sulphate. In the outer jar when the sulphuric acid is added to the bichromate of potash the following reaction takes place :—

$K_2Cr_2O_7$	+	H_2O	+	H_2SO_4
One molecule of bichromate of potash	and	one molecule of water	and	one molecule of sulphuric acid

=	K_2SO_4	+	$2H_2CrO_4$
form	one molecule of potassium sulphate	and	two molecules of chromic acid.

The potassium sulphate is a harmless bye-product which dissolves in the solution and gives no further trouble, therefore in the subsequent expressions it will be ignored :—

Inner cell :—

$3Zn$	+	$3H_2SO_4$	=	$3ZnSO_4$	+	$3H_2$
molecules of zinc	and	three molecules of sulphuric acid	form	three molecules of zinc sulphate	and	six atoms of hydrogen.

This hydrogen makes its appearance in the outer compartment where it meets the depolarizing fluid.

$3H_2$	+	$2H_2CrO_4$	+	$3H_2SO_4$
Six atoms of hydrogen	and	two molecules of chromic acid	and	three molecules of sulphuric acid

=	$Cr_2(SO_4)_3$	+	$8H_2O$
form	one molecule of chromium sulphate	and	eight molecules of water.

The reactions in the outer jar, which are somewhat complicated, may be summarized as follows :—The hydrogen upon its liberation at the carbon plate meets the mixture of chromic and sulphuric acids. It combines with some of the oxygen of the chromic acid so forming water. The remainder of the chromic acid combines with the sulphuric acid to form chromium sulphate.

Practical Notes.—In charging the cell four ounces of bichromate paste are placed in the outer jar, and to this paste is added dilute sulphuric acid (one part acid to six parts water).

The strength of the acid solution in the porous pot is one part of acid to forty parts of water by measure. The levels of the inner and outer solutions should be the same, and the latter should be about two inches below the top of the jar.

The reactions previously described are only true in the case of a cell maintained in efficient condition. If neglected, or too heavily worked without being replenished, a totally

different set of reactions will ensue, resulting in the formation of crystals of chrome alum upon the carbon plate. The E.M.F. and internal resistance of the cell are both most seriously affected, and the action should be guarded against. The immediate cause of the secondary reactions is that the solution has become super-saturated, and this may be prevented by the occasional withdrawal of some of the solution and its replacement by dilute sulphuric acid. Any crystals of chrome alum which may have formed should be removed when attending to the cell. If the solution loses its orange tint and turns blue this is an indication that more bichromate paste is required, whilst the failure of the cell when its solution still retains its normal orange hue indicates a deficiency of sulphuric acid. The zinc of any cell in proper condition is always bright and clean. The blue-coloured solution taken in conjunction with a zinc covered with a dirty deposit indicates that the cell must be cleaned out and made up afresh. An insufficiency of mercury causes defective amalgamation, and consequently the zinc is not as uniformly consumed as it should be.

Three-pint Bichromate.

For special purposes (*e. g.* parts of multiplex circuits) a larger form of bichromate cell is required. The jar is of the three-pint size, and contains two porous pots, each equipped with a zinc, and two carbons are placed in the outer part. The two zincs and the two carbons are respectively connected together. The effect of the arrangement is to considerably reduce the internal resistance, and at the same time provide a largely-increased current capacity. The internal resistance is reduced because the volume of liquid between the plates has been increased, whilst the distance from each positive to each negative is practically unchanged. The current capacity is increased because the quantity of chemicals, and hence the quantity of chemical energy, has been augmented.

Dry Cells.

The whole of the cells belonging to this class are modifications of the Leclanché, and have precisely the same electro-chemical reactions. Their generic title is due to

the fact that the interior is not liquid as in the case of the ordinary or wet cells previously described. The exciting and depolarizing materials are applied in the form of damp pastes. If these substances were actually dry the cell would not be capable of supplying a current on account of the enormous internal resistance, which might, with propriety, be regarded as infinite.

A consideration of the various types of cell subsequently described will show that various substances have been combined with the constituents of an ordinary Leclanché cell, and it may be remarked that the objects which they are designed to fulfil are firstly to keep the interior moist, and secondly to prevent the generation of gases. The similarity of the E.M.F. of the various forms of dry and Leclanché agglomerate cells is a clear indication that their main chemical actions are identical. The secondary actions are very probably complicated due to the presence of the various substances alluded to.

The term "dry cell" is sometimes regarded as a misnomer, because the cell is not actually dry, but in comparison with a cell with liquid electrolyte it may reasonably be allowed to pass. They are now universally known as dry cells, and may be defined as cells in which the exciting and depolarizing materials are held in a damp gelatinous condition.

The Gassner Dry Cell.—This cell, which made its appearance in 1888, was the first successful dry cell. It consists of a containing vessel of zinc, forming the positive element of the cell, and holding the carbon block. The space between the elements is filled up by a jelly consisting of zinc oxide, ammonium chloride, sulphate of lime, chloride of zinc, and water and manganese dioxide.

The E.C.C. Dry Cell.—The containing vessel is of zinc, and serves also as the positive element. A flat carbon plate is placed in the centre of the vessel, and a layer of insulating material covers the whole of the bottom of the zinc vessel, thus preventing direct contact between the elements. The carbon plate is surrounded by a damp black paste nearly 60 per cent. of which consists of manganese dioxide and carbon dust. The balance (40 %) is chiefly made up of the oxides of silicon, iron, magnesium, and calcium, together with water. The white or exciting paste con-

sists of lime, ammonia, water, and salammoniac. A piece of thick paper is laid on the top of the paste, and this is covered with cotton wool, above which the cell is sealed with bitumen, two small vent-holes being left for the escape of any gases generated.

The zinc vessel is contained in a cardboard box. The general appearance of the complete cell is illustrated in Fig. 9.

FIG. 9.—E.C.C. dry cell.

The Hellesen Dry Cell.—This cell consists of a hollow circular carbon, the interior of which is filled with silicated cotton, and surrounded first with a black paste, then with a white paste, and finally a square zinc containing vessel. The whole cell is then packed with sawdust into a slightly larger carbon box, and the top is run in with pitch. The black paste consists chiefly of carbon and manganese dioxide, with the salts of silicon, magnesium, calcium, and iron. The white paste consists of water, lime, ammonia, and the oxides of zinc and magnesium.

The Obach Dry Cell (Figs. 10 and 11) consists of a zinc cylinder of a thickness suitable to the size of the cell, with a connection wire attached to the inside of the cylinder. This latter contains a carbon rod, surrounded by a depolarizer, composed of a mixture of powdered peroxide of manganese and carbon intimately mixed and pressed into close contact with the carbon rod. A brass terminal is fixed into the top of the carbon in the following manner:— A verticle hole is provided in the rod into which the pin of the terminal is inserted, and a molten alloy, composed of bismuth, lead and tin, is poured around the pin. As this alloy expands slightly in cooling, it establishes a perfect contact between the pin and the carbon. An exciting paste composed of plaster of Paris and flour mixed with a solution of ammonium chloride surrounds the depolarizer. A space is provided in the upper part of the cell to receive

the gases and water which are formed during the working of the cell, and this space is filled with sawdust as an absorbent for the moisture. The cell is sealed at the top with a layer of bitumen, small holes being provided for the escape of the gases. The cell is contained in a strong cardboard box impregnated with paraffin wax, which makes it damp-proof, and thus insulates the cell. The cells are remarkable for their large output.

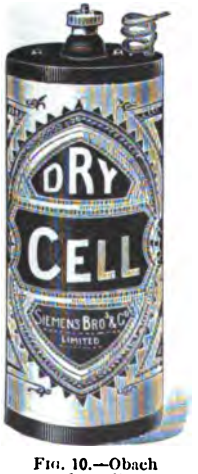

FIG. 10.—Obach dry cell.

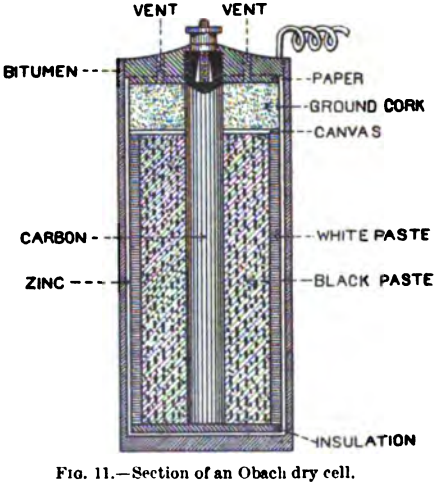

FIG. 11.—Section of an Obach dry cell.

STANDARD CELLS.

A particular combination of materials in a cell will always produce the same E.M.F. provided the materials are exactly alike. In the form of cell invented by Latimer Clark it is a *sine qua non* that all the materials employed shall be chemically pure. Under these conditions the E.M.F. of the cell is 1·434 volts at 15° C. The cell is usually very small, and is often made in a short wide test tube. Into the bottom of the test tube a short piece of platinum wire is fused. The outer part of this wire forms the positive terminal and the inner serves to make connection with the negative element, metallic mercury, which

covers it. Above the mercury a thick paste of mercurous sulphate is spread, and above this is a paste of zinc sulphate into which the zinc rod dips. The zinc rod passes through the cork or bung, and the whole arrangement is sealed up.

The chemical action of the cell is due to the SO_4 of the exciting fluid (zinc sulphate) combining with the positive element to form zinc sulphate and liberate zinc which combines with the mercurous sulphate to form zinc sulphate and mercury. The mercury so formed merely adds to the

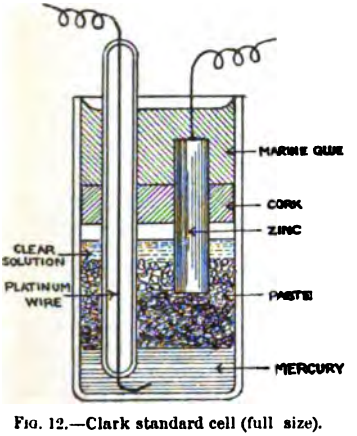

FIG. 12.—Clark standard cell (full size).

FIG. 13.—Pair of Clark cells and thermometer.

quantity already present. There is a very large number of modifications of the Clark cell in existence, but in principle they do not vary at all. The final form given to such a cell is illustrated in Fig. 13, and it will be noticed that a thermometer has been added for ascertaining the temperature of the cells, since this has an important influence upon the value of the E.M.F.

A full size section of the Board of Trade form of cell is shown in Fig. 12, whilst the subsequent figure shows the general appearance of a pair of cells mounted in the usual way with a thermometer. The official directions for the construction of the cell are given upon the subsequent page :—

SPECIFICATION B.

On the Preparation of the Clark Cell.

Definition of the Cell.

The cell consists of zinc or an amalgam of zinc with mercury and of mercury in a neutral saturated solution of zinc sulphate and mercurous sulphate in water, prepared with mercurous sulphate in excess.

Preparation of the Materials.

1. *The Mercury.*—To secure purity it should be first treated with acid in the usual manner, and subsequently distilled in vacuo.

2. *The Zinc.*—Take a portion of a rod of pure redistilled zinc, solder to one end a piece of copper wire, clean the whole with glass paper or a steel burnisher, carefully removing any loose pieces of the zinc. Just before making up the cell dip the zinc into dilute sulphuric acid, wash with distilled water, and dry with a clean cloth or filter paper.

3. *The Mercurous Sulphate.*—Take mercurous sulphate, purchased as pure, mix with it a small quantity of pure mercury, and wash the whole thoroughly with cold distilled water by agitation in a bottle; drain off the water, and repeat the process at least twice. After the last washing, drain off as much of the water as possible.

4. *The Zinc Sulphate Solution.*—Prepare a *neutral* saturated solution of pure ("pure recrystallized") zinc sulphate by mixing in a flask distilled water with nearly twice its weight of crystals of pure zinc sulphate, and adding zinc oxide in the proportion of about 2 per cent. by weight of the zinc sulphate crystals to neutralize any free acid. The crystals should be dissolved with the aid of gentle heat, but the temperature to which the solution is raised should not exceed 30° C. Mercurous sulphate treated as described in 3 should be added in the proportion of about 12 per cent. by weight of the zinc sulphate crystals to neutralize any free zinc oxide remaining, and the solution filtered, while still warm, into a stock bottle. Crystals should form as it cools.

5. *The Mercurous Sulphate and Zinc Sulphate Paste.*—Mix the washed mercurous sulphate with the zinc sulphate solution, adding sufficient crystals of zinc sulphate from the stock bottle to ensure saturation, and a small quantity of pure mercury. Shake these up well together to form a paste of the consistence of cream. Heat the paste, but not above a temperature of 30° C. Keep the paste for an hour at this temperature, agitating it from time to time, then allow it to cool; continue to shake it occasionally while it is cooling. Crystals of zinc sulphate should then be distinctly visible, and should be distributed throughout the mass; if this is not the case add more crystals from the stock bottle, and repeat the whole process.

This method insures the formation of a saturated solution of zinc and mercurous sulphates in water.

To set up the Cell.

The cell may conveniently be set up in a small test tube of about 2 cm. diameter and 4 cm. or 5 cm. deep. Place the mercury in the bottom of this tube, filling it to a depth of say 0·5 cm. Cut a cork about 0·5 cm.

thick to fit the tube; at one side of the cork bore a hole through which the zinc rod can pass tightly; at the other side bore another hole for the glass tube which covers the platinum wire; at the edge of the cork cut a nick through which the air can pass when the cork is pushed into the tube. Wash the cork thoroughly with warm water, and leave it to soak in water for some hours before use. Pass the zinc rod about 1 cm. through the cork.

Contact is made with the mercury by means of a platinum wire about No. 22 gauge. This is protected from contact with the other materials of the cell by being sealed into a glass tube. The ends of the wire project from the ends of the tube; one end forms the terminal, the other end and a portion of the glass tube dip into the mercury.

Clean the glass tube and platinum wire carefully, then heat the exposed end of the platinum red hot, and insert it in the mercury in the test tube, taking care that the whole of the exposed platinum is covered.

Shake up the paste and introduce it without contact with the upper part of the walls of the test tube, filling the tube above the mercury to a depth of rather more than 1 cm.

Then insert the cork and zinc rod, passing the glass tube through the hole prepared for it. Push the cork gently down until its lower surface is nearly in contact with the liquid. The air will thus be nearly all expelled, and the cell should be left in this condition for at least 24 hours before sealing, which should be done as follows:—

Melt some marine glue until it is fluid enough to pour by its own weight, and pour it into the test tube above the cork, using sufficient to cover completely the zinc and soldering. The glass tube containing the platinum wire should project some way above the top of the marine glue.

The cell may be sealed in a more permanent manner by coating the marine glue, when it is set, with a solution of sodium silicate, and leaving it to harden.

The cell thus set up may be mounted in any desirable manner. It is convenient to arrange the mounting so that the cell may be immersed in a water-bath up to the level of, say, the upper surface of the cork. Its temperature can then be determined more accurately than is possible when the cell is in air.

In using the cell sudden variations of temperature should as far as possible be avoided.

The form of the vessel containing the cell may be varied. In the H form, the zinc is replaced by an amalgam of 10 parts by weight of zinc to 90 of mercury. The other materials should be prepared as already described. Contact is made with the amalgam in one leg of the cell, and with the mercury in the other, by means of platinum wires sealed through the glass.

Daniell Standard Cells.

Modifications of the Daniell cell have been used by some physicists with excellent results, but its use has not been very extensive.

A standard cell which is required for accurate work should only be used to produce a current through very

high resistances, *i. e.* resistances of the order of 100,000$^{\omega}$. Even then the current should only be maintained for the shortest possible time. Neglect of these precautions entails inaccuracy in the value of the assumed E.M.F.

Where the highest accuracy is not essential less delicate apparatus may be employed. For example, the P.O. tangent galvanometer requires far too large a current to produce a satisfactory deflection with such a cell as Clark's. To provide a standard E.M.F. and one capable of supplying a current of a milli-ampere the P.O. standard Daniell was designed and for many years was extensively employed by the Department. This cell, though far less accurate than a Clark cell used under the best conditions, was sufficiently so for its purpose. The zinc and its porous pot (Fig. 14) were kept in one compartment and the copper in another, and the parts of the cell were only assembled when the cell was actually in use. The lid carried a projection which made it impossible to close the cell until the porous pot containing the zinc and the copper plate had been replaced in their receptacles.

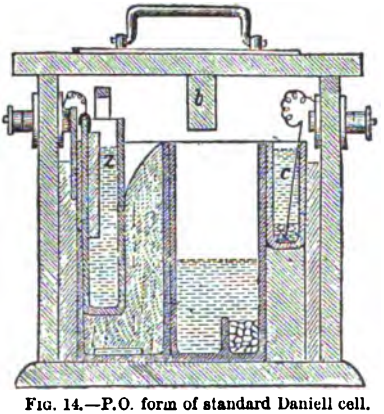

FIG. 14.—P.O. form of standard Daniell cell.

Special care was taken that the constituent parts of the cell and the chemicals employed were as pure as possible. The exciting fluid was a saturated solution of zinc sulphate. This cell has been replaced by a dry cell whose E.M.F. is periodically measured by accurate apparatus. (See Chapter III.)

CHARACTERISTICS OF CELLS USED BY THE POST OFFICE.

The E.M.F. of a cell decreases and the internal resistance rises as the cell becomes exhausted, and it is therefore

necessary to define the point at which the cell should be considered faulty. Again, bad materials or defective porous pots adversely affect the E.M.F. and internal resistance. A pot which is of a too porous character permits the excitant and depolarizer to rapidly commingle. A very hard one, on the other hand, unduly increases the internal resistance of the cell. Cells are considered faulty if their E.M.F.s fall below the minimum value given in the table upon page 40. They are also considered faulty if their internal resistances rise above the maximum or fall below the minimum value; the latter is usually due to the porous pots being too soft.

The particulars, characteristics and purposes for which the various classes of cells are employed is set forth in tabular form upon page 40.

Leclanché cells polarize if heavily worked, since the hydrogen appears at the carbon plate more rapidly than the manganese can dispose of it. With intervals of rest or for small currents the cell possesses many advantages, notably the entire absence of local action when not in use and the very small amount of attention necessary. For use upon single needle and double plate sounder circuits, where the work is usually of an intermittent character, the cell is without a rival.

The Daniell cell is remarkable for the very small amount of polarization which occurs even when heavily worked. It is also notorious for the very considerable amount of local action which always occurs. Its comparatively low E.M.F. and high internal resistance render it unfitted for purposes where heavy currents are necessary. The small size was formerly employed for simplex sounder circuits, whilst the large size was used for ordinary duplex circuits and for local batteries generally. Owing to its local action and the more frequent attention required it would not be as satisfactory as the Leclanché cell for single needle and double plate sounder stations.

The Bichromate cell is used wherever large currents, sustained for considerable periods, are required. It is most efficient when it is heavily worked, but owing to the frequent and skilled attention required it is unsuitable for general use. It also suffers from local action, but scarcely to the same extent as the Daniell.

TABULATED COMPARISON OF CELLS USED BY THE POST OFFICE.

Type of Cell.	Element. +	Element. −	Exciting Fluid.	Depolarizer.	E.M.F. (volts). max.	E.M.F. (volts). min.	E.M.F. (volts). Fall per cent	Internal Res. (ohms). max.	Internal Res. (ohms). min.	Local Action.	Polarization.	Purposes for which used.
Bic.	Zn	C	Dilute H_2SO_4	H_2SO_4 / H_2CrO_4	2.16	1·836	15	4 / 1·5	2 / ·5	Moderate.	Moderate.	High speed, Quadruplex Multiplex, Long duplex, Sounder locals, Universal working.
Dan.	,,	Cu	Water	Solution $CuSO_4$	1·08	·972	10	S 8 / L 4	2 / 2	Great.	Very small.	Sounders simplex and duplex. Local batteries generally.
LEC. P.P.	,,	C	Solution NH_4Cl	MnO_2	1·62	1·08	33	4	—	Nil.	Large.	SN, DPS, Receiving news circuits, Bells.
LEC. Agg.	,,	,,	,,	,,	1·62	1·08	33	·8	—	Nil.	Considerable.	Speaking batteries for telephones.
Dry.	,,	,,	Paste NH_4Cl	,,	1·62	1·08	33	Not tested.		Nil.	Moderate.	Special arrangements.

It may be remarked that the internal resistance of a battery affects the speed of working of a circuit (*vide* Chapter XVII.). If too low the transmitter sparks, whilst too high a value reduces the working speed. To obtain an E.M.F. of 100^{v}, 105 Daniell cells would be required as against 55 Bichromate cells. The internal resistances in the two cases would be from 110$^{\omega}$ to 220$^{\omega}$ with Bichromates, and from 210$^{\omega}$ to 420$^{\omega}$ with Daniells.

Dry cells possess the advantage of portability and are eminently suitable for special arrangements. Indeed they may be employed for almost any purpose. Since the internal resistance is very low a 10$^{\omega}$ resistance coil is placed in every 10-cell box, so that excessive currents may not be produced. If the 10$^{\omega}$ coils were omitted when the cells were used in conjunction with a Wheatstone transmitter, the excessive sparking would at once put the transmitter out of action.

Ideal Cell.

There is no form of primary battery which fulfils all the conditions one would desire from an ideal point of view, and therefore it happens that the choice of a battery largely depends upon the uses to which it is to be put. An ideal cell should possess the following characteristics :—

1. High E.M.F.
2. Low internal resistance.
3. Absence of polarization.
4. Absence of local action.
5. Cost of the cell small.
6. Cost of charging small.
7. Amount of energy obtained per charge should be large.
8. Attention required should be little.
9. No injurious fumes should be given off.
10. The materials should be easily and safely handled.
11. Dimensions as small as possible.

Conditions 6 and 7 mean that the cost of a given quantity of electrical energy should be as low as possible, and conditions 7 and 8 specify that the labour cost of maintenance shall be small. For telegraph purposes the prime cost, and

the cost of maintenance are very important matters, since the number of cells in use is so enormous. The annual cost of maintenance (chemicals and labour) for the three types of cell employed by the Department may be said to lie within the limits stated below :—

Leclanché,	6*d.*	per cell per annum.
Daniell,	1*s.* to 1*s.* 6*d.*	,, ,,
Bichromate,	2*s.* 3*d.* to 2*s.* 6*d.*	,, ,,

These figures all refer to the cost of maintaining cells in a large office. Where they are scattered over a wide area the cost is far more, since the time occupied in travelling is considerable. Roughly speaking, one Bichromate cell will, on account of its high E.M.F., do the work of two Daniell cells, but the frequent skilled attention required and the powerful acids used render it utterly unfit for use in any local office.

Taking into account the cost of the boxes used with Leclanché and Bichromate batteries, the average cost per cell of a Daniell only exceeds that of a Bichromate battery by 10%, whilst Leclanché No. 1 cells occupy an intermediate position between the two.

CHAPTER II

CALCULATIONS IN CONNECTION WITH CIRCUITS AND CONDUCTORS.

PART I.—ARRANGEMENT OF CELLS.

Size of Cell.

THE E.M.F. of a cell is entirely independent of its dimensions, so that a cell consisting of a grain of zinc and a percussion cap would have just the same E.M.F. as a cell composed of the same materials, but as large as a Lancashire boiler. The internal resistances in these two cases would differ very widely, as also would the amount of electrical energy obtainable from each. The quantity of energy obtainable from any cell is the product of its average E.M.F., its average current, and the time that it supplies that current. The actual value obtained will differ considerably according to the conditions chosen.

The method adopted by the Post Office takes account of the differences in the dimensions of the various cells tested. It will be obvious that, given two cells of similar type but of different size, the larger cell will furnish a given current for a longer period than the smaller one. Not only so, but, at any period during the discharge, the larger cell is subjected to a less severe test, since its resources, *i. e.* the quantities of active material, are much greater.

The Post Office test consists in adjusting the external resistance so that the current is equal to 1 m.a. per cubic inch of the volume of the cell. The resistance is frequently adjusted so as to maintain the current at this constant value, and the test ceases immediately the E.M.F. falls below the minimum value for that type of cell (see p. 40). The current is then multiplied by the duration of the discharge,

and the value so obtained represents the capacity of the cell in ampere-hours. The capacity of a No. 1 Leclanché cell is 48·96 ampere-hours, whilst that of a Bichromate is 19·9, and that of an Obach B dry cell 40.

The cost of the energy per unit is readily obtained from the results of these tests taken in conjunction with the initial cost of the cell and its value when exhausted. With wet cells the cost per charge and that of renewals and maintenance somewhat complicates the problem, but the general principle is sufficiently apparent.

In any particular type of cell the internal resistance will be small with a large-sized cell and large with a small-sized cell. The reason of this will be quite obvious after a consideration of the principles enunciated upon page 64. The larger the plates are made the wider or broader is the intervening liquid as compared with the distance between the plates, the former corresponding to sectional area in the case of a wire.

Three Methods of Joining-up Cells.

There are three ways in which cells may be arranged, firstly in series, secondly in parallel, and thirdly in parallel-series or multiple arc, this method being a combination of the first and second methods.

Cells in Series.

The series method consists in connecting the copper of the first cell to the zinc of the second cell, and connecting the copper of the second to the zinc of the third, leaving the latter's copper pole free. The zinc of the first cell and the copper of the last cell form the poles of the battery. The conventional symbol universally employed to denote a battery consists of a long thin stroke to represent the positive plate of a cell and a short thick line or an outlined oblong of the same size to represent the negative plate. Three cells, illustrated in Fig. 15, are joined up in series, and it will be observed that in this case the cells all tend to send their current in the same direction. Each cell therefore adds its pressure to that of the others, but, in so doing, also adds its own internal resistance. The total E.M.F. produced by a battery, consisting of a number

of cells joined in series, is equal to the E.M.F. of one cell multiplied by the number of cells in series, whilst the total internal resistance is equal to the internal resistance of one cell multiplied by the number in series.

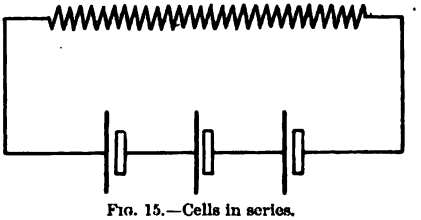

FIG. 15.—Cells in series.

If the E.M.F. and internal resistance of each of the three cells shown in Fig. 15 is respectively 1 volt and 6 ohms the total E.M.F. of the battery will be $1 \times 3 = 3$ volts, and its internal resistance will be $6 \times 3 = 18$.

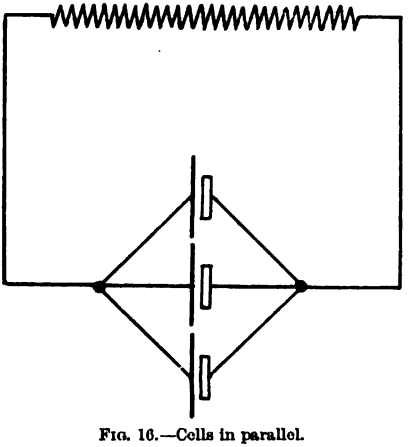

FIG. 16.—Cells in parallel.

CELLS IN PARALLEL.

The parallel method consists in joining all the positive poles together and similarly connecting all the negative poles. The circuit to be energized is then joined between the grouped positive and negative poles of the cells. In this case the pressures are not cumulative as in the series

method. The total E.M.F. of the arrangement is the E.M.F. of one cell, but the total internal resistance is the internal resistance of one cell divided by the number in parallel. For instance, if the three cells shown in Fig. 16 each have an E.M.F. of one volt and an internal resistance of six ohms, the total E.M.F. and internal resistance of the arrangement will be respectively 1 volt and $\frac{6}{3}^{\omega}$, *i. e.* 2 ohms.

Cells in Multiple Arc.

The parallel-series or multiple-arc method of joining up

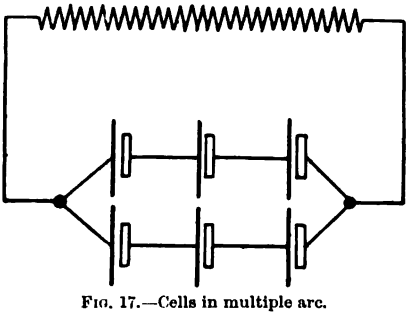

Fig. 17.—Cells in multiple arc.

cells consists in putting in parallel two or more batteries, each consisting of an equal number of cells joined in series. In Fig. 17 six cells have been connected up in multiple arc. The arrangement obviously consists of two batteries, of three cells in series each, connected in parallel. Using the same values as before for the E.M.F. and internal resistance per cell it will be seen that the total E.M.F. and total internal resistance of either of the three-cell batteries separately considered will be as before (Fig. 15), 3 volts and 18^{ω} respectively. The question now becomes—what will be the effect of putting two such batteries in parallel ? The rule given for cells in parallel may be applied to batteries in parallel, and the answer is therefore :—

Total E.M.F. = that of one battery, viz. 3 volts.

Total Internal resistance = that of one battery divided by the number of similar batteries in parallel, *i. e.*

$$\frac{18^{\omega}}{2} = 9^{\omega}.$$

In all examples of the parallel-series type the total E.M.F. is equal to the E.M.F. per cell multiplied by the number in series, and the total internal resistance is equal to the internal resistance per cell multiplied by the number of cells in series and divided by the number of similar sets or rows in parallel. Had there been six rows in the above example then the E.M.F. would have been 3 volts as before, but the internal resistance would have been reduced to 3^{ω}.

In practical telegraphy there are but few cases where it is necessary to join batteries in parallel, and the term battery is usually employed to denote cells in series. For instance a "5-cell Daniell" means five cells joined up in series, and "two 5-cell Daniells in parallel" would therefore mean two batteries, consisting of five cells in series each, connected in parallel, *i. e.* 2 rows in parallel each row consisting of five cells in series.

Method in which to join up Cells under different circumstances.

The three methods of joining up cells each have their particular utility, and although the parallel method is never, and the parallel series method but seldom, used in practical telegraphy, it is still desirable to briefly state the conditions under which each arrangement should be employed.

The maximum current which can be obtained from any particular cell is reached when the cell is short circuited and is equal to its E.M.F. divided by its internal resistance. Similarly if a million cells be placed in series and short circuited the maximum current will be the same, for whilst the E.M.F. has been increased a million-fold the internal resistance has been similarly increased.

If it is required to obtain a larger current from the cells they must be placed in parallel. Every cell which is added increases the current, for although the E.M.F. remains the same, the internal resistance is reduced by every fresh cell. If, now, the current produced by a number of cells joined up in series and flowing through a circuit of enormously high resistance is considered it will at once be seen that the internal resistance of the cells is insignificant in comparison with the enormous external resistance

postulated. Each cell added in series will therefore increase the current flowing in the circuit. Upon the other hand, the only effect of joining cells in parallel is to reduce the total internal resistance, and this is of no consequence in comparison with the external resistance. The E.M.F. remains the same, and consequently the addition of cells in parallel means no practical increase in the current available.

It will now be clear that, for resistances large in comparison with that of the cell, the cells should be joined in series, whilst for a low resistance the cells should be joined in parallel, *i. e.* in order to obtain the maximum current from the minimum number of cells.

Between the extremes already discussed come the cases where parallel series arrangements are necessary. The rule, which may be deduced from Ohm's law, relating to this case is that the arrangement of cells which gives an internal resistance most nearly approximating to the external resistance will furnish the maximum current. To give a numerical example :—Suppose that it is desired to know how best to join up forty cells, each having an E.M.F. of 2 volts and an internal resistance of 12·5ω to a circuit having a resistance of 20ω.

The forty cells may be joined up in the following ways :—(*a*) all in parallel, (*b*) all in series, (*c*) two rows in parallel each of 20 in series, (*d*) four rows in parallel each of 10 in series, (*e*) five rows in parallel each of 8 in series, (*f*) eight rows in parallel each of 5 in series.

With the arrangement (*e*) the internal resistance of the battery is the same as the external resistance, viz. 20ω, and this gives the maximum current, viz. 400 m.a. The currents for each of the arrangements are (*a*) 98·5 m.a., (*b*) 153·8 m.a., (*c*) 275·8, (*d*) 390·2, (*e*) 400 m.a., (*f*) 359·6 m.a.

From that which has been said it follows that the maximum amount of power obtainable from any battery is greatest when the external resistance is equal to the internal resistance. When this is the case the efficiency is 50 %, because there is as much energy lost in overcoming the internal resistance of the battery as is available in the external circuit.

With a given number of cells the maximum current is obtained through a given external resistance when the

number of cells in series (n) is equal to the square root of the total number of cells (N) multiplied by the external resistance (R) divided by the internal resistance per cell (r).

$$n = \sqrt{\frac{N \times R}{r}}$$

The result obtained in the previous example may be found by application of this formula thus :—

$$\sqrt{\frac{40 \times 20}{12{\cdot}5}} = \sqrt{64} = 8 \text{ in series.}$$

The number of rows is obtained by dividing the total number of cells by the number per row, *i. e.* by the number in series.

When a fractional answer is obtained the nearest whole number which will give a whole number when divided into the total number of cells must be chosen.

Example.—How should sixty cells, having an E.M.F. of 1·5 volts and an internal resistance of 2$^{\omega}$ per cell, be arranged so as to provide the maximum possible current through an external resistance of ·55$^{\omega}$?

$$\sqrt{\frac{60 \times {\cdot}55}{2}} = \sqrt{16{\cdot}5} = 4{\cdot}06.$$

The whole number which will divide into 60 and give a whole number as quotient are 1, 2, 3, 4, 5, 6, 10, 12, 15, 20, and 60. 4·06 is nearer to 4 than to any other of these numbers and the best arrangement is therefore fifteen rows each of four cells in series.

CELLS WRONGLY JOINED UP AND SPECIAL ARRANGEMENTS.

In each of the foregoing cases the cells have been correctly joined up. It will now be well to consider one or two simple cases of wrong connection. If, in joining a number of cells in series, some of the cells are reversed, the total E.M.F. will be reduced whilst the total internal resistance will be unaffected. The E.M.F. will be equal to the E.M.F. of the larger number acting in one direction, less the E.M.F. of the smaller number acting in the opposite direction. Where the numbers are equal the E.M.F.s will balance and

no current will result, that is, of course, supposing that the E.M.F.s per cell are equal.

Example.—Ten cells joined in series, E.M.F. 1 volt and internal resistance 5ω per cell, are connected to a resistance of 50ω. What current will be produced if two of the cells are reversed?

E.M.F. of larger number of cells = 8v
„ of lesser „ „ = 2v

Total E.M.F. of combination = 6v

$$\text{Current} = \frac{6^v}{50 + 50} = \cdot 06 \text{ ampere.}$$

In certain cases a combination of parallel and series methods of joining up might be adopted, as, for instance, where a number of small cells are used in conjunction with a number of cells of larger size.

Example.—What will be the total E.M.F. and internal resistance produced by joining two 5-cell Large Daniells in series with two 10-cell Small Daniell batteries placed in parallel? E.M.F. 1 volt per cell. Internal resistance Large 5ω Small 10ω per cell.

Total E.M.F. of two 10-cell Small Daniells in parallel = 10v
„ „ of two 5-cell Large Daniells in series = 10v
Total E.M.F. of above in series = 20v

Internal resistance of Large Daniells = $5^\omega \times 10 = 50^\omega$

„ „ Small Daniells = $\frac{10^\omega \times 10}{2} = 50^\omega$

Total internal resistance of above in series = 100ω.

In other words this combination is equivalent to four 5-cell Large Daniell batteries joined in series.

In the above case the batteries placed in parallel had the same E.M.F. Where this is not the case, the battery of higher E.M.F. drives a current through the battery of lower E.M.F. Such an arrangement is most inefficient and is never intentionally used in practice, although it occasionally occurs by accident.

A simple rule for calculating the current due to such an arrangement is that the two batteries are equivalent, as

regards the external circuit, to a new battery whose E.M.F. equals the E.M.F. of one of them multiplied by the resistance of the other plus the E.M.F. of the latter multiplied by the resistance of the former, the sum being divided by the sum of their internal resistances, whilst the internal resistance of this new battery is equal to the joint resistance of the two batteries.*

NUMBER OF CELLS REQUIRED TO FURNISH A GIVEN CURRENT.

It is frequently necessary to find the number of cells which will be required to furnish a given current through a certain external resistance. If the internal resistance of the cells required is negligible—as in the case of secondary cells—the required number of cells is obtained by ascertaining the voltage necessary and then dividing it by the E.M.F. per cell.

Example.—How many secondary cells will be required to furnish a current of 20 m.a. through a circuit of 1536$^{\omega}$?

Note.—E.M.F. per cell should be taken as 2 volts.

$$\text{Current} \times \text{resistance} = \text{E.M.F. required}$$

$$\cdot 02 \times 1536 = 30{\cdot}72 \text{ volts.}$$

$$\frac{\text{Total E.M.F.}}{\text{E.M.F. per cell}} = \text{Number of cells}$$

$$\frac{30{\cdot}72}{2} = 15{\cdot}36, \textit{ i. e. } 16 \text{ cells.}$$

The answer 15·36 is not practical because a special cell having an E.M.F. of ·36 of the E.M.F. of 2 volts would

* The value of the current C in the external circuit is also given by the following equation :—

$$C = \frac{e_1 r_2 + e_2 r_1}{r_1 r_2 + r_1 r_3 + r_2 r_3}$$

where e_1 = E.M.F. of first cell
e_2 = ,, second cell
r_1 = Internal resistance of first cell.
r_2 = ,, ,, second cell.
r_3 = External resistance.

If the two cells are joined up so that the cells combine together in series the numerator of the equation should be altered to $e_1 r_2 - e_2 r_1$. From this, it follows that when no current flows through the external circuit the ratio of the E.M.F.s of the two cells is equal to the ratio of their internal resistances.

have to be designed, and therefore the smallest whole number in excess of the result is taken.

In the case of primary cells the internal resistance cannot usually be ignored and the procedure shown above cannot be followed, because the total resistance of the circuit is not known until the number of cells in circuit is ascertained. The calculation of the current through a circuit connected to a battery consisting of a number of cells in series has been shown on page 48. By the aid of a little elementary algebra the following rule can readily be obtained :*—

$$\text{Number of cells} = \frac{\text{External resistance}}{\frac{\text{E.M.F. per cell}}{\text{Current required}} - \text{Internal res. per cell}},$$

i. e. divide the E.M.F. per cell by the current required (in amperes), and from this deduct the internal resistance per cell. The number of cells required is then equal to the external resistance divided by the result of the first operation.

Example.—How many cells E.M.F. 1^{v} per cell and internal resistance 10$^{\omega}$ per cell will be required to provide a current of 15 m.a. through a resistance of 1200$^{\omega}$?

$$\frac{1200}{\frac{1}{\cdot 015} - 10} = 21{\cdot}18, \textit{ i. e. } 22 \text{ cells.}$$

The result obtained from wrongly using the simplified formula applicable to cases where the internal resistance is negligible would have been 18 cells. The same remarks apply to the fractional result as before, save that in this case the internal resistance of the special cell would also have to be proportionally less. The current produced by 22 cells will be slightly in excess of 15 m.a., whilst that supplied by 21 cells would be very slightly less than the specified value.

A minimum value for the E.M.F. and a maximum value for the internal resistance of each type of cell was given in Chapter I. A cell having these values is not considered to

* $\frac{ne}{nr + R} = C \therefore n = \frac{R}{\frac{e}{C} - r}$ where n = number of cells in series, r = internal res. per cell, R = external res., and C = current in amperes.

be faulty, and although the average values given by an efficiently maintained battery would be far better than these, it is clearly necessary to recognize that the worst values may obtain. In order that the specified current shall always be produced upon a telegraph circuit, the minimum value of the E.M.F. per cell and the maximum value of the internal resistance per cell are always taken in working out the battery power.

Example.—What power will be required to work a double current set through a line 100 miles of 100 lb. copper line?

Resistance of wire	=	878$^{\omega}$
,, ,, the two earths	=	20$^{\omega}$
,, ,, two galvanometers	=	60$^{\omega}$
,, ,, one relay	=	400$^{\omega}$
Total external resistance	=	1358$^{\omega}$

Large Daniells E.M.F. ·972^{v}, internal resistance 4$^{\omega}$ per cell are employed. 14 m.a. required.

$$\text{Number of cells required} = \frac{1358}{\frac{\cdot 972}{\cdot 014} - 4}$$

$$= 20{\cdot}76$$

or 21 cells.

In practice 22 cells would be employed, probably made up of four five-cell and one two-cell batteries.

Special Cases.

The internal resistance of the battery employed upon telegraph circuits is nearly always much less than that of the external circuit, and therefore the cells are generally arranged in simple series. In such cases the formula given above is always applicable, and the result obtained may be accepted without question. Where, however, the internal resistance approaches or approximates to that of the external circuit a certain amount of caution is necessary. This condition is fortunately indicated by the formula. If the E.M.F. per cell divided by the current is not at least twice the value of the internal resistance per cell, then a multiple-series arrangement is necessary. If the internal resistance is greater

than the first-named quantity, the current cannot be provided by cells in simple series. The maximum current is obtained from a cell when it is short circuited, and this current is the same as that obtained from, say, a thousand cells placed in series and short circuited.

The internal resistance of a number of cells in multiple arc is :—

$$\frac{\text{Internal resistance per cell}}{\text{Number of rows}} \times \text{Number in series.}$$

(This is identically the same as the statement on page 47.)

A battery consisting of two rows of cells in parallel is equivalent to one battery (in simple series), having the same number of cells as one row of the former, but having an internal resistance equal to half that of the former per cell.

This forms the key to the solution of such a problem as the following :—

Example.—How many cells having an E.M.F. of two volts and an internal resistance of 10ω per cell will be required to furnish a current of 400 m.a. through an external resistance of 18ω ?

Simple series :—

$$\frac{18}{\frac{2}{\cdot 4} - 10} = \frac{18}{5 - 10}$$

Denominator negative, therefore simple series will not meet the case.

Two rows :—

$$\frac{18}{5 - 5} = \text{Infinity.}$$

Three rows :—

$$\frac{18}{5 - 3\frac{1}{3}} = 10{\cdot}8, \textit{ i.e.}\ 11 \text{ cells.}$$

Note.—E.M.F. ÷ current is *less* than twice the internal resistance.

Four rows :—

$$\frac{18}{5 - 2\frac{1}{2}} = 7{\cdot}2, \textit{ i.e.}\ 8 \text{ cells.}$$

Five rows :—

$$\frac{18}{5-2} = 6 \text{ cells.}$$

Six rows :—

$$\frac{18}{5-1\frac{2}{3}} = 5{\cdot}4, \textit{ i. e. } 6 \text{ cells.}$$

The total number of cells required is as follows :—

Three rows	33
Four rows	32
Five rows	30
Six rows	36

The arrangement with five rows gives the smallest number of cells, and is therefore to be preferred. Where two different arrangements give the same result it is well to remember that the resistance of a primary battery will rise towards the end of its discharge, and therefore the arrangement with the lower value of internal resistance should be chosen. It may also be noted that the larger the number of rows the smaller is the current provided by each cell.

PART II.—JOINT RESISTANCE AND DIVISION OF CURRENT.

The total resistance offered by circuits or conductors placed in series is equal to the sum of their separate resistances. For instance, the total resistance of the conductors depicted in Fig. 18 is 1623Ω.

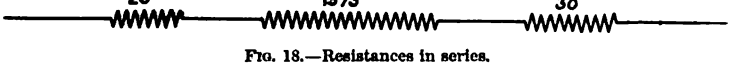

FIG. 18.—Resistances in series.

Before dealing with resistances in parallel it is necessary to define some of the important terms which are commonly employed.

Conductance has exactly the opposite meaning to resist-

ance, and may be defined as the inverse of resistance. From this definition it follows that

$$\text{Conductance} = \frac{1}{\text{Resistance}}$$

$$\text{and Resistance} = \frac{1}{\text{Conductance.}}$$

The unit of resistance is the "ohm," and that of conductance is the "mho," which is "ohm" written backwards. A circuit having a resistance of one ohm has a conductance of one mho, so that the two units themselves have the same numerical value in this case. A circuit having a resistance of 10^{ω} has a conductance of $\frac{1}{10}$ mho, whilst a circuit having a resistance of $\frac{1}{10}^{\omega}$ would have a conductance of 10 mhos.

This definition of conductance is extremely useful in making clear the methods of finding the resistance of a number of paths in parallel and the proportion in which a given value of current will divide amongst them.

It has been found that *the total conductance of a number of paths in parallel is equal to the sum of their separate conductances.* The joint resistance or total resistance offered by the combination of paths is therefore the reciprocal of their total conductance, which latter is obtained by adding together the conductance of each path.

An example of the application of these rules is appended:

What is the joint resistance of four paths having resistances of respectively 2^{ω}, 3^{ω}, 4^{ω}, and 5^{ω} placed in parallel?

Total conductance = sum of separate conductances

" " $= \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \frac{1}{5}$ mho.

$$\text{Resistance} = \frac{1}{\text{Conductance}}$$

$$\text{Joint resistance} = \frac{1}{\text{Total conductance}} = \frac{1}{\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+\frac{1}{5}} \text{ ohm.}$$

$$= \frac{1}{\frac{77}{60}} = \frac{60}{77} \text{ ohm.}$$

In the case of a number of paths of equal resistance placed in parallel inspection of the previous example will at once

reveal the fact that their joint resistance is equal to the resistance of one of them divided by the number of paths in parallel. For instance the joint resistance of ten 1000$^{\omega}$ paths placed in parallel is $\frac{1000}{10} = 100^{\omega}$.

Another very useful rule may, with the aid of a little simple algebra, be deduced from the rule on p. 56. It is that *the resistance of two paths in parallel is equal to their product divided by their sum.* An example of its application is given below :—

What is the joint resistance of a 50$^{\omega}$ path in parallel with a 150$^{\omega}$ path?

$$\text{Joint res.} = \frac{\text{Product}}{\text{Sum}} = \frac{50 \times 150}{50 + 150} = \frac{7500}{200} = 37{\cdot}5^{\omega}.$$

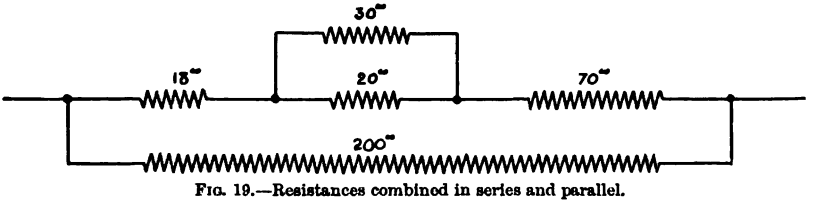

FIG. 19.—Resistances combined in series and parallel.

A formula could be deduced for three, four, five, or any number of paths, but the complication involved is too great since a separate formula would have to be memorized for each.

A problem which occasionally crops up in practice is that in which the joint resistance and the resistance of one of the two paths in parallel only are known. From this information the resistance of the other path may readily be obtained.

It has already been stated that the total conductance is equal to the sum of the separate conductances. In the case of two circuits in parallel the total conductance is equal to the conductance of the two added together. Hence the conductance of one of the circuits is clearly equal to the total conductance, less the conductance of the other circuit.

An example is appended :—The joint resistance of two paths in parallel is 20$^{\omega}$, and the resistance of one of

them is known to be 30ω. Find the resistance of the other path.

Conductance of first circuit = total conductance − conductance of second circuit.

$$\text{Conductance of first circuit} = \frac{1}{20} - \frac{1}{30} \text{ mho}$$

$$\therefore \text{Resistance of first circuit} = \frac{1}{\frac{1}{20} - \frac{1}{30}} \text{ ohms}$$

$$= 60\omega$$

An example of a somewhat complicated circuit is shown in Fig. 19. The total resistance of the arrangement is equal to the joint resistance of 200ω and the resistance of the remainder of the circuit. The example would be worked as follows:—

$$\text{Joint resistance of } 20\omega \text{ and } 30\omega \text{ paths} = \frac{20 \times 30}{20 + 30} = 12\omega$$

$$\text{Total resistance of upper path} = 18 + 12 + 70 = 100\omega$$

$$\text{Resistance of whole combination} = \frac{100 \times 200}{100 + 200}$$

$$= 66\tfrac{2}{3}\omega$$

From the extensions of Ohm's law known as Kirchoff's laws it can readily be shown that *a current divides between a number of paths in parallel in direct proportion to their respective conductances.* An example of the application of this rule is given below:—

A current of 10 amperes divides between four paths in parallel whose resistances are respectively 3ω, 4ω, 5ω, and 6ω. What is the value of the current in each path?

The conditions of the problem are shown in Fig. 20.

Resistances of paths	3ω	4ω	5ω	6ω
Conductances of paths	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{5}$	$\frac{1}{6}$
The 10 amperes divide as	$\frac{1}{3}$:	$\frac{1}{4}$:	$\frac{1}{5}$:	$\frac{1}{6}$
Bringing to common denominator	$\frac{20}{60}$:	$\frac{15}{60}$:	$\frac{12}{60}$:	$\frac{10}{60}$
The 10 amperes divide as	20 :	15 :	12 :	10

$\therefore$ if the total current splits into $20 + 15 + 12 + 10 = 57$ parts,

the current through each path is respectively $\frac{20}{57}$, $\frac{15}{57}$, $\frac{12}{57}$, $\frac{10}{57}$ of 10 amperes.

i.e. $3\frac{20}{57}$, $2\frac{36}{57}$, $2\frac{6}{57}$, $1\frac{43}{57}$ amperes.

Obviously if this result is correct the sum of the currents should be 10 amperes, and by trial it will be found to be so. The current in the 6ω path should be half that in the 3ω path. These points enable one to rapidly test the accuracy of the arithmetic involved.

A useful rule, the accuracy of which may readily be checked by the above methods, is that by which the current through two paths A and B in parallel may be at once

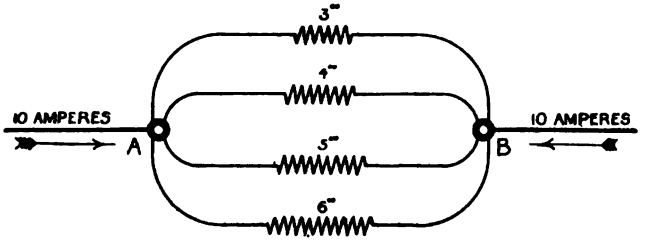

FIG. 20.—Division of current between paths in parallel.

written down without calculation. The current through A is $\frac{B}{A+B}$ of the total current, and that through B is $\frac{A}{A+B}$ of the total current, *e.g.*

A current of 10 amperes divides between two paths of 2ω and 3ω placed in parallel. What is the current in each?

In the 2ω path $\frac{3}{2+3}$ of 10 amps = 6 amperes.

In the 3ω path $\frac{2}{2+3}$ of 10 amps = 4 amperes.

It is sometimes necessary to deduce the resistance of a path of unknown resistance, placed in parallel with another of known resistance, from a knowledge of the

proportion in which a current divides between them. It has been previously pointed out that the current splits in direct proportion to the conductances of the paths. The converse of this is obviously true, viz. that the conductances of paths in parallel are proportional to the currents in each. An example is given below :—

The currents in two paths in parallel are respectively 10 amperes and 8 amperes. If the resistance of the highest path is 40 ohms, what is the resistance of the other?

Currents in the paths respectively 10 and 8 amperes

$\therefore$ Conductances of the paths 10 : 8

The conductance of the better path $= \frac{10}{8}$ of the other.

$$\text{Conductance of other path} = \frac{1}{40}$$

$$\therefore \text{Conductance of better path} = \frac{10}{8} \text{ of } \frac{1}{40}$$

$$= \frac{1}{32} \text{ mho}$$

$$\text{Resistance of better path} = 32 \text{ ohms}$$

Another method of working this problem is given in order to clearly demonstrate a useful fact in connection with circuits in parallel. Referring again to Fig. 20; the difference of potential between A and B can have but one value, since were this not the case either the point A or the point B would have two different potentials at one time. This is clearly impossible, hence the current in each path multiplied by its resistance gives the difference of potential between its ends, and this is the same for all the paths. Practically, this statement means that Ohm's law may be applied to a part of a circuit. Had there been batteries inserted in the paths the question would have been a little more complicated.

The working of the previous example by means of the facts stated above is appended.

Resistance of highest path 40 ohms
Current in „ „ 8 amperes

Difference of potential between its ends $40 \times 8 = 320$ volts.

$$R = \frac{E}{C} \therefore \text{Resistance of other path } \frac{320}{10} = 32^{\omega}.$$

The current sent through any circuit by a battery is equal to its E.M.F. divided by the total resistance of the circuit. This total resistance is made up of the internal resistance of the battery and the external resistance. For instance, a battery having an E.M.F. of 20^{v} and an internal resistance of 100^{ω} applied to a circuit of 400^{ω} will produce a current of $\frac{20}{100 + 400}$ or 40 m.a. The joint resistance of the circuits in parallel is the external resistance, as in the following example :—

Example.—What current will be produced in each of four circuits of respectively 20^{ω}, 30^{ω}, 100^{ω} and 150^{ω} resistance joined in parallel to three five-cell Large Daniell batteries also joined in parallel? E.M.F. per cell one volt. Internal resistance 6^{ω} per cell.

E.M.F. of battery $= 1^{v} \times 5 = 5$ volts.

Internal resistance $= \frac{6 \times 5}{3} = 10^{\omega}$

Resistances of paths	20^{ω}	30^{ω}	100^{ω}	150^{ω}
Conductances of paths	$\frac{1}{20}$	$\frac{1}{30}$	$\frac{1}{100}$	$\frac{1}{150}$
Bringing to common denominator	$\frac{15}{300}$	$\frac{10}{300}$	$\frac{3}{300}$	$\frac{2}{300}$

$$\text{Total conductance} = \frac{15 + 10 + 3 + 2}{300} = \frac{30}{300}$$

$$\text{Joint resistance} = \frac{300}{30} = 10^{\omega}$$

$$\text{Total current} = \frac{5}{10 + 10} = \frac{5}{20} = 250 \text{ m.a.}$$

The current splits as $15 : 10 : 3 : 2$

$\therefore$ if 250 m.a. splits into $15 + 10 + 3 + 2 = 30$ parts the current through each path is respectively $\frac{15}{30}$, $\frac{10}{30}$, $\frac{3}{30}$, $\frac{2}{30}$, of 250 m.a.

i. e. 125 m.a. 83·3 m.a. 25 m.a. 16·7 m.a.

Whilst dealing with batteries and circuits it will perhaps be well to deduce the relations which exist between the E.M.F. of a battery and the difference of potential between its terminals when connected to a completed circuit. This may best be done by considering a definite case. A battery having an E.M.F. of 2 volts and an internal resistance of 12$^{\omega}$ is connected to a circuit having a resistance of 8$^{\omega}$ (Fig. 21). The current through the circuit is $\frac{2}{12+8} = \cdot 1$ ampere. The difference of potential between the ends of the external resistance is, by Ohm's law, $\cdot 1 \times 8^{\omega} = \cdot 8$ volt. This is a difference of potential observable at the terminals of the

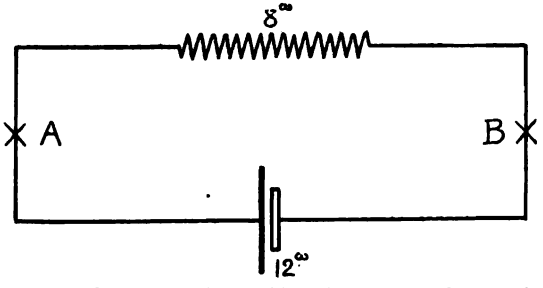

FIG. 21.—If the E.M.F. of the cell is 2^{v} the difference of potential between *A* and *B* is ·8^{v}.

cell when the circuit is closed. The difference between this value and that of the E.M.F. of the battery on open circuit is the E.M.F. which is lost in traversing the resistance of the battery. The current inside the battery is obviously the same as that in the external circuit, viz. ·1 ampere. Hence the value of the E.M.F. taken up in the battery itself is $\cdot 1 \times 12^{\omega} = 1 \cdot 2$ volts, which is the value deduced from the difference between the E.M.F. on open and closed circuit. In any case of this character the whole of the E.M.F. of the cell must be accounted for.

From a knowledge of the E.M.F. of a battery upon open circuit and the differences of potential across its terminals when connected by a known resistance, the value of its internal resistance can readily be calculated. This is the principle employed in one method of measuring internal resistance. A numerical example is appended :—

Example.—The E.M.F. of a battery upon open circuit is 30 volts, but when the circuit is closed through an external resistance of 70$^{\omega}$ the difference of potential falls to 23 volts. What is its internal resistance?

Method I.

E.M.F. of battery = 30^{v}
P.D. across 70$^{\omega}$ = 23^{v}
E.M.F. lost in battery itself = 30 − 23 = 7^{v}
Current in battery and in 70$^{\omega}$ circuit is the same.
∴ By Ohm's law 23 : 7 : : 70 : Internal res.

$$\text{Internal res.} = \frac{7}{23} \times 70$$

$$= 21{\cdot}3^{\omega} \text{ approx.}$$

Method II.

E.M.F. of battery = 30^{v}
P.D. across 70$^{\omega}$ = 23^{v}
E.M.F. lost in battery itself = 30 − 23 = 7^{v}

$$\text{Current through } 70^{\omega} = \frac{PD}{70} = \frac{23}{70} \text{ ampere}$$

$$\text{Internal resistance of battery} = \frac{\text{E.M.F. lost}}{\text{Current}} = \frac{7}{\frac{23}{70}}$$

$$= 21{\cdot}3^{\omega} \text{ approx.}$$

PART III.—THE RESISTANCE OF WIRES OF VARYING DIMENSIONS.

It has been found by experiment that the resistance which any conductor offers to an electric current depends upon three factors, viz.:—

1. Its dimensions.
2. Its composition.
3. Its temperature.

If the resistance of any material of known dimensions has a certain value at a particular temperature then it is a

matter of ease to deduce the value of the resistance which will be offered by that material when given different dimensions at the same temperature. The changes produced by altering the temperature have been carefully determined for all the substances in common use for electrical purposes. It will therefore be seen that if the resistance of any substance of known dimensions is stated for any given temperature the determination of its resistance when made into any particular form is merely a matter of arithmetic.

Experiment proves that *the resistance of a conductor of uniform gauge is directly proportional to its length and inversely proportional to its sectional area.* It is, of course, assumed that the temperature and composition do not vary. This condition will apply to all the problems given unless otherwise specified.

In order to shorten and simplify the various proportions stated the following letters will be employed to denote the values of the resistances and dimensions stated opposite them—

l_1	to represent	the length	of	the first wire.
l_2	,,	,,	,,	second wire.
a_1	,,	sectional area	of	the first wire.
a_2	,,	,,	,,	second wire.
d_1	,,	diameter	,,	first wire.
d_2	,,	,,	,,	second wire.
w_1	,,	total weight	,,	first wire.
w_2	,,	,,	,,	second wire.
R_1	,,	resistance	,,	first wire.
R_2	,,	,,	,,	second wire.

Example 1.—If the resistance of 10 miles of wire is 89$^{\omega}$, what is the resistance of 7 miles of similar wire?

$$\begin{array}{lcccccc} & l_1 & : & l_2 & :: & R_1 & : & R_2 \\ i.e. & 10 & : & 7 & :: & 89 & : & R_2 \end{array}$$

$$\therefore R_2 = \frac{7 \times 89}{10} = 62{\cdot}3^{\omega}.$$

Example 2.—Two wires of similar gauge and material offer resistances of 40$^{\omega}$ and 28$^{\omega}$. If the former is 360 yards long, what is the length of the second wire?

$$\begin{array}{rcl} & R_1 : R_2 :: l_1 : l_2 \\ i.e. & 40 : 28 :: 360 : l_2 \end{array}$$

$$\therefore \quad l_2 = \frac{28 \times 360}{40} = 252 \text{ yards.}$$

Example 3.—Two wires of equal length have sectional areas of ·12 square inch and ·15 square inch respectively. If the resistance of the smaller wire is 10ω, what is the resistance of the larger?

$$\begin{array}{rcl} & a_2 : a_1 :: R_1 : R_2 \\ i.e. & \cdot 15 : \cdot 12 :: 10 : R_2 \end{array}$$

$$\therefore R_2 = \frac{\cdot 12 \times 10}{\cdot 15} = 8\omega.$$

Given both resistances and the area of one wire the area of the second would be found in similar fashion.

Example 4.—A wire 12 miles long having a sectional area of ·021 square inch has a resistance of 7·5 ohms. What will be the resistance of a similar wire 18 miles long having a sectional area of ·023 square inch?

$$\begin{array}{rcl} & l_1 : l_2 :: R_1 : R_2 \\ \text{also} & a_2 : a_1 :: R_1 : R_2 \\ \therefore & l_1 \times a_2 : l_2 \times a_1 :: R_1 : R_2 \\ i.e. & 12 \times \cdot 023 : 18 \times \cdot 021 :: 7 \cdot 5 : R_2 \end{array}$$

$$\therefore \quad R_2 = \frac{18 \times \cdot 021 \times 7 \cdot 5}{12 \times \cdot 023} = 10 \cdot 27\omega.$$

The sectional area of a round wire is equal to the square of its diameter multiplied by ·7854, hence it will be obvious that *the resistance of a conductor of uniform gauge is proportional to its length and inversely proportional to the square of its diameter.*

Examples of the application of this rule are appended.

Example 5.—What will be the resistance of a wire 26 yards long having a diameter of 33 mils if the resistance of a wire of the same material 52 miles long with a diameter of ·01 inch has a resistance of 32ω?

Note.—In comparing either two lengths or two diameters the units of each dimension chosen should be the same, but it is not necessary that all four quantities should be in the same unit. A mil is one-thousandth of one inch.

·01 inch = 10 mils.

$$l_2 : l_1 :: R_2 : R_1$$

and $$(d_1)^2 : (d_2)^2 :: R_2 : R_1$$

$$\therefore \quad l_2 \times (d_1)^2 : l_1 \times (d_2)^2 :: R_2 : R_1$$

$$(52 \times 1760) \times 33^2 : 26 \times 10^2 :: 32 : R_1$$

$$\therefore \quad R_1 = \frac{26 \times 10^2 \times 32}{52 \times 1760 \times 33^2}$$

$$= \cdot 0008348^{\omega} \text{ or } 834{\cdot}8 \text{ microhms.}$$

In problems where the lengths of the two wires are equal the proportion reduces to :—

$$(d_2)^2 : (d_1)^2 :: R_1 : R_2.$$

Example 6.—A wire 30 miles long, 40 mils in diameter has a resistance of 1000ω. What is the length of a wire of the same material having a resistance of 200ω and a diameter of 25 mils?

$$R_1 : R_2 :: l_1 \times (d_2)^2 : l_2 \times (d_1)^2$$

$$i.e. \quad 1000 : 200 :: 30 \times 25^2 : l_2 \times 40^2$$

$$\therefore \quad l_2 \times 40^2 = \frac{200 \times 30 \times 25^2}{1000}$$

$$l_2 = \frac{200 \times 30 \times 25^2}{1000 \times 40^2}$$

$$= 2{\cdot}344 \text{ miles approx.}$$

Example 7.—The resistance of an iron wire 20 miles long, having a diameter of 171 mils is 266·4ω. What is the diameter of a wire 3 miles long having a resistance of 79·92ω?

$$R_2 : R_1 :: l_2 \times (d_1)^2 : l_1 \times (d_2)^2$$

$$i.e. \quad 79{\cdot}92 : 266{\cdot}4 :: 3 \times 171^2 : 20 \times (d_2)^2$$

$$\therefore \quad 20 \times (d_2)^2 = \frac{266{\cdot}4 \times 3 \times 171^2}{79{\cdot}92}$$

$$(d_2)^2 = \frac{266{\cdot}4 \times 3 \times 171^2}{79{\cdot}92 \times 20}$$

$$\therefore \quad d = \sqrt{14620} = 121 \text{ mils approx.}$$

Example 8.—What is the diameter of a wire 7 miles long having the same resistance as a wire 20 miles long which has a diameter of 60 mils?

$$l_1 : l_2 :: R_1 : R_2$$

and $$(d_2)^2 : (d_1)^2 :: R_1 : R_2$$

Since $$R_1 = R_2$$

then $$l_1 : l_2 :: (d_2)^2 : (d_1)^2$$

i.e. $$20 : 7 :: 60^2 : (d_1)^2$$

$$\therefore (d_1)^2 = \frac{7 \times 60^2}{20}$$

and $$d_1 = \sqrt{\frac{7 \times 60^2}{20}} = 35{\cdot}5 \text{ mils approx.}$$

Where the diameter of one wire and the sectional area of another is given it is obviously necessary to reduce both to the same dimension. It has been previously stated that the area of a circle is equal to ·7854 times its diameter. An example in which these complications arise is given below :—

Example 9.—A wire 17 miles long, diameter 171 mils has a resistance of 230ω. What is the resistance of a similar wire 152 yards long having a sectional area of ·02 square inch ?

Note.—As in the previous problem both lengths must be in the same units. A similar remark also applies to the diameters.

Preliminary calculations.

The area of a circle $= \frac{\pi}{4} \times$ (diameter)^2.

$$\pi = 3{\cdot}1416 \therefore \frac{\pi}{4} = {\cdot}7854.$$

Diameter of wire = 171 mils = ·171 inch.

Area of wire ·171 inch in diameter = $·7854 \times ·171^2$ = ·023 square inch.

As in example 4.

$$l_1 \times a_2 : l_2 \times a_1 :: R_1 : R_2$$

i.e. $$17 \times 1760 \times {\cdot}02 : 152 \times {\cdot}023 :: 230 : R_2$$

$$\therefore R_2 = \frac{152 \times {\cdot}023 \times 230}{17 \times 1760 \times {\cdot}02} = 1{\cdot}34\omega$$

The rules given for the comparison of the resistances of wires of differing dimensions are merely deductions from the experimentally determined equation given overleaf :—

$$R = \frac{l \times S}{a}$$

where l = length of conductor (inches or cms.).
a = sectional area of conductor (inches or cms.).
S = specific resistance or resistivity, as it is now termed (cubic inches or c. cms.).
R = resistance of conductor in ohms.

If l and a are made unity then R is equal to S, hence resistivity of any substance is the resistance between the opposite faces of a unit cube of that material. Since both inches and centimetres are in daily use as units it is necessary to specify the unit employed. The resistivity of a substance is therefore defined as so many microhms per cubic inch or per cubic centimetre, according to the unit chosen. It is scarcely necessary to remark that l, a, and S must all be in either centimetres or inches and not a compound of both.

The resistivities of a few materials, taken from the observations of Dewar and Fleming, are given below:—

Material.	Resistivity at 0° C.	
	Microhms per cubic inch.	Microhms per cubic centimetre.
Silver (electrolytic)	·57795	1·468
Copper* ,,	·61457	1 561
Gold	·86496	2·197
Aluminium	1·049	2·665
Zinc	2·2642	5·751
Nickel (electrolytic)	2·7303	6 935
Iron	3·5689	9·065
Tin (pressed)	5·137	13·048
Lead (pressed)	8·0236	20·38
Mercury	37·04	94·07
German silver	8 to 12	20 to 30
Graphite	118 to 157	300 to 400
Saturated solution of sulphate of copper	$11{\cdot}535 \times 10^6$	$29{\cdot}3 \times 10^6$
Saturated solution of sulphate of zinc	$13{\cdot}268 \times 10^6$	$33{\cdot}7 \times 10^6$

* Matthiessen's standard of ·153858 standard ohms resistance for a wire 1 metre long, weighing 1 gramme at 60° F. is taken as the standard

Example 10.—What is the resistance of one mile of copper wire 112 mils in diameter, given the resistivity as ·681327 microhms per cubic inch?

$$R = \frac{(1760 \times 36) \times \cdot 681327}{\cdot 7854 \times (\cdot 112)^2} \text{ microhms}$$
$$= 4{,}382{,}000 \text{ microhms approx.}$$
$$= 4 \cdot 382\Omega.$$

It may also be well to note that the statement upon page 68 may be written in the following form :—

$$\text{Specific resistance (per cubic inch or per cubic cm.)} = \frac{\text{Res. in ohms} \times \text{area (inches or cms.)}}{\text{Length (inches or cms.)}}$$

All quantities must be in *inches* or *all* in *centimetres*.

An example of the application of these facts is appended.

Example 11.—Compare the specific resistances of iron and copper, given that 1 mile of iron wire 171 mils in diameter has a resistance of 13·32 ohms, whilst a mile of copper wire having a diameter of 97 mils has a resistance of 5·855 ohms.

$$\text{Specific res. of iron per cubic inch} = \frac{13 \cdot 32 \times (\cdot 171^2 \times \cdot 7854)}{1760 \times 36}$$
$$= 4 \cdot 829 \text{ microhms approx.}$$
$$\text{Specific res. of copper per cub. inch} = \frac{5 \cdot 855 \times (\cdot 097^2 \times \cdot 7854)}{1760 \times 36}$$
$$= \cdot 6829 \text{ microhms approx.}$$

Answer. 4·828 : ·6829
or 7·07 : 1

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for hard drawn high conductivity commercial copper. Its specific gravity at this temperature is taken as such that the weight of a cubic foot is 555 lbs. The resistance of annealed high conductivity commercial copper is ·66788 microhm per cubic inch, and 1·69639 microhms per cubic centimetre, whilst the corresponding values for hard drawn copper are respectively ·681327 and 1·73054 microhms. (See report of the British Representative Committee on Copper Conductors in Munro and Jamieson's Pocket-book, or in the *Journal* of the Institution of Electrical Engineers.)

The resistivity of pure iron is 10·616 microhms per cubic centimetre. One mile of pure iron wire having a resistance of one ohm weighs 4656 lbs. whilst an ohm-mile of commercial wire should not weigh more than 5328 lbs. (See page 71.)

This may also be expressed by the statement that the iron has a conductivity equal to 14·14% of that of the copper.

There is still another way in which the gauge of a wire may be specified, and this is by stating its weight per unit length. This method is adopted by the Department, and it will therefore be necessary to consider the relations between the length, weight and resistance of a wire.

The weight of a wire of uniform section is directly proportional to its cubic contents, *i.e.* to its length multiplied by its sectional area. It has already been stated that the resistance of a wire is directly proportional to its length divided by the square of its diameter. If both the numerator and denominator of a fraction are multiplied by the same quantity the value of the fraction is unaltered, therefore the relation may be re-stated thus :—the resistance of a wire varies directly as the square of its length, and inversely as the product of its length and its diameter squared. The latter quantity is directly proportional to its weight, hence the rule becomes :—*the resistance of a conductor of uniform gauge is directly proportional to the square of its length and inversely as its total weight.*

If two wires of the same total weight are respectively one and two yards long, then their resistances will be as one is to four. Not only is the length of wire greater in the second case, but its gauge is less since it is obvious that the same quantity of metal is spread over two yards instead of one.

An example of the application of the above rule is appended :—

Example 12.—A wire 80 yards long weighing 30 lbs. has a resistance of 2ω. What will be the resistance of a similar wire 60 yards long weighing only 12 lbs. ?

$$(l_1)^2 \;:\; (l_2)^2 \;::\; R_1 \;:\; R_2$$

and

$$w_2 \;:\; w_1 \;::\; R_1 \;:\; R_2$$

$$\therefore\ (l_1)^2 \times w_2 \;:\; (l_2) \times w_1 \;::\; R_1 \;:\; R_2$$

$$i.e.\ 80^2 \times 12 \;:\; 60^2 \times 30 \;::\; 2 \;:\; R_2$$

$$\therefore R_2 = \frac{60^2 \times 30 \times 2}{80^2 \times 12} = 2{\cdot}8125^{\omega}$$

When applying these rules care must be taken to express the weights of both wires as *total* weights. As will be shown later, the *weight per mile* specifies the gauge of the conductor, and its resistance is therefore proportional to the simple length.

Example 13.—A wire 1500 yards long weighing 300 lbs. per mile has a resistance of 3Ω. What resistance will be offered by a wire of similar material 80 yards long having a total weight of 1 cwt. ?

Total weight of 1500 yards of wire weighing 300 lbs. per mile $= \frac{1500 \times 300}{1760}$.

$$(l_1)^2 \ : \ (l_2)^2 \ :: \ R_1 \ : \ R_2$$

and $$w_2 \ : \ w_1 \ :: \ R_1 \ : \ R_2$$

$$\therefore \ (l_1)^2 \times w_2 \ : \ (l_2)^2 \times w_1 \ :: \ R_1 \ : \ R_2$$

$$1500^2 \times 112 \ : \ 80^2 \times \frac{1500 \times 300}{1760} \ :: \ 3 \ : \ R_2$$

$$\therefore R_2 = \frac{80^2 \times \frac{1500 \times 300}{1760} \times 3}{1500^2 \times 112} = \tfrac{3}{154} = \cdot 01948\Omega$$

The weight of a wire of given length and material is proportional to its sectional area. It will therefore be evident that the rule given upon page 64 may also be written "*the resistance of a conductor of uniform gauge varies directly as its length and inversely as its weight per mile.*" The application of the rule is so obvious in view of examples 1 to 4 that no illustrations should be necessary.

In practice the various sizes of wire are named by their weights per mile. For instance, an iron wire weighing 400 lbs. per mile is termed a "400 lb. iron wire." As the resistance per mile of any particular kind of wire is inversely proportional to its weight per mile it will therefore seem that the two quantities when multiplied together will always give the same result. Hence by remembering this number for iron and for copper the resistance of all the various sizes of wire used by the Department may be memorized. The number is 5328 for iron and 878·2 for copper wire.

The resistance of a 400 lb. iron wire is therefore $\frac{5328}{400} = 13{\cdot}32^{\omega}$, a 200 lb. iron wire similarly is $\frac{5328}{200} = 26{\cdot}64^{\omega}$, *i. e.* twice the resistance of the former.

The resistance of a 100 lb. copper wire is $\frac{878{\cdot}2}{100} = 8{\cdot}782^{\omega}$ per mile, and of a 150 lb. wire $\frac{878{\cdot}2}{150} = 5{\cdot}885^{\omega}$ per mile.

The copper wire of commerce is not chemically pure and the presence of impurities increases its resistance. Instead of defining the specific resistance per cubic inch a conductivity of 99% of that of pure copper is often specified.

From either the specific resistance per cubic centimetre or per cubic inch the resistance of any wire of that material may be calculated. In the same way, from the resistance of a foot of wire weighing one grain similar information may be deduced. This latter value is perhaps more useful in the case of conductors whose gauges are specified by their weights per mile.

The resistance of a foot-grain of pure hard drawn copper wire is $\cdot2205^{\omega}$, and of pure iron $1{\cdot}169^{\omega}$.

The corresponding resistivity formula is :—

$$R = \frac{l^2 \times W}{w}$$

where l = length in feet
W = resistance of one foot of wire weighing one grain (7000 grains = 1 lb.)
w = total weight in grains.

Example 14.—Find the resistance of a copper wire 1 mile long weighing 100 lbs.

$$R = \frac{(1760 \times 3)^2 \times \cdot2205}{100 \times 7000}$$
$$= 8{\cdot}782 \text{ ohms.}$$

There is one other class of problem which is occasionally met with. In this the weight and diameter of a wire is specified. The relation is that *the resistance varies directly*

*as the total weight, and inversely as the fourth power of the diameter.**

Example 15.—Two wires weighing 80 lbs. and 60 lbs. have diameters respectively 100 and 40 mils. If the resistance of the thicker wire is 10^{ω}, what is the resistance of the other?

$$w_1 : w_2 :: R_1 : R_2$$
$$(d_2)^4 : (d_1)^4 :: R_1 : R_2$$
$$\therefore w_1 \times (d_2)^4 : w_2 \times (d_1)^4 :: R_1 : R_2$$
$$i.e.\ 80 \times 40^4 : 60 \times 100^4 :: 10 : R_2$$
$$\therefore R_2 = \frac{60 \times 100^4 \times 10}{80 \times 40^4} = 293^{\omega} \text{ approx.}$$

Example 16.—Two wires having resistances of 256^{ω} and 81^{ω} weigh respectively 10 lbs. and 25 lbs. If the diameter of the first wire is 30 mils, what is the diameter of the second?

$$R_2 : R_1 :: w_2 : w_1$$
$$R_2 : R_1 :: (d_1)^4 : (d_2)^4$$
$$\therefore R_2 : R_1 :: w_2 \times (d_1)^4 : w_1 \times (d_2)^4$$
$$81 : 256 :: 25 \times 30^4 : 10 \times (d_2)^4$$
$$10 \times (d_2)^4 = \frac{256 \times 25 \times 30^4}{81}$$
$$(d_2)^4 = \frac{256 \times 25 \times 30^4}{81 \times 10}$$
$$d = \sqrt[4]{\frac{256 \times 25 \times 30^4}{81 \times 10}}$$
$$= 50{\cdot}3 \text{ mils approx.}$$

---

* w is proportional to $l \times a$

$\therefore$ l is proportional to $\frac{w}{a}$

Now R is proportional to $\frac{l}{a}$.

Substituting for l,

R is proportional to $\frac{\frac{w}{a}}{a} = \frac{w}{a^2}$.

The sectional area is proportional to d^2,

$\therefore$ R is proportional to $\frac{W}{d^4}$.

Application of Laws to Cells.

A consideration of the laws governing the resistance of wires of varying dimensions makes it obvious why a large cell has a lower internal resistance than a smaller one of the same type. The larger the plates the broader is the liquid between them as compared with the intervening distance. The former corresponds to the sectional area of the wire.

Effect of Temperature upon Resistance.

The temperature was assumed to be the same in all the problems dealt with, and it is therefore necessary that the effect of varying the temperature should now be considered. In the case of all metals the resistance rises as the temperature is increased. In the case of copper wire the resistance increases about ·428 per cent. per degree for each degree Centigrade, or ·238 per cent. for each degree Fahrenheit. A more accurate formula is :—

$$R_t = R_{32}\left\{1 + \cdot0023708 \times (t - 32) + \cdot00000034548 \times (t - 32)^2\right\}$$

where R_t = Resistance at "t°" F.
and R_{32} = ,, ,, 32° F.

(The numerical coefficients were determined experimentally.)

Example 17.—What is the resistance of a copper conductor at 52° F. if its resistance is 1000$^{\omega}$ at 32° F.?

$$R_t = 1000\left\{1 + \cdot0023708 \times 20 + \cdot00000034548 \times 20^2\right\}$$
$$= 1047\cdot554192^{\omega}.$$

By approximate rule (·238% per degree F.)

$$\text{Increase} = \frac{1000}{100} \times \cdot238 \times 20$$
$$= 47\cdot6^{\omega}$$
$$\therefore R_t = 1047\cdot6^{\omega}.$$

In the case of carbon the resistance decreases with the temperature, and a similar remark applies to most liquid conductors, mercury being excepted. The warming of

most insulators decreases their insulating power, *i. e.* lowers their specific resistances.

The effect of changes of temperature is far more marked with insulators than with conductors, for whilst an increase of 15° F. would raise the resistance of a 1000ᵐ copper conductor to 1036ᵐ, a gutta-percha core would decrease from 9000 to 1000 megohms with the same rise in temperature. The equation connecting the resistances of insulators is of the exponential type, and varies largely with the quality as well as with the kind of material.*

In the case of gutta-percha the effect of pressure is very great. The insulation of a submerged submarine cable greatly exceeds that observed at the factory. The deeper the cable is laid the higher is its insulation resistance. This effect is due solely to the pressure exerted by the water, and amounts to $61\frac{1}{4}\%$ per 1000 fathoms depth. Thus a cable having an insulation of 100 megohms at atmospheric pressure would have a resistance $222\frac{1}{2}$ megohms when laid at a depth of 2000 fathoms. India-rubber, on the other hand, decreases in resistance, when subjected to pressure, at the rate of about 16% per 1000 fathoms.

Changes of temperature and pressure are found not to affect the true capacity of a G.P. cable. With india-rubber, a rise in temperature from 100° F. to 212° F. increased the capacity 140% (Kempe).

PART IV.—ELECTROMAGNETS.†

A magnetic field is generated by a loop of wire conveying a current. The value of the field produced may be augmented by increasing the number of turns of wire.

It is now necessary to also consider the effect of introducing an iron core into the coil of wire or solenoid, as it is termed, in this connection. Iron and steel conduct lines of

* *Handbook of Electrical Testing*, by H. R. Kempe, 6th edition, p. 470.

† Before reading this part of the chapter the reader should be familiar with the facts illustrated by Fig. 27.

force far better than does air, and a somewhat similar form of law to Ohm's law for electrical circuits applies to magnetic circuits. A magnetic circuit may be defined as the path of the magnetic lines of force. The law for a magnetic circuit is:—

$$\frac{\text{Magneto-motive force}}{\text{Reluctance}} = \text{Flux}$$

The magneto-motive force corresponds to E.M.F., the reluctance or magnetic resistance to resistance and the flux or number of lines of force flowing through the magnetic circuit to the current. The reluctance of a circuit is directly proportional to its length, and inversely proportional to the product of its sectional area and its permeability. The permeability corresponds roughly to conductivity, and may be defined as the relative conductivity of the material under consideration, and that of air which is taken as unity. There is, however, a most important difference between an electric circuit and a magnetic circuit. The resistance of any particular conductor is the same for any value of current, so long as its temperature remains constant. In the case of a magnetic circuit the value varies with the magnetizing force. For instance, with a magnetizing force of 2, the permeability is 2500, whilst with 350 it has fallen to 54. The reason of these changes in value will be found in the description of the molecular theory of magnetism.

The magnetizing force of a solenoid is 1·257 times the total number of ampere turns, *i.e.* 1·257 × current in amperes × number of convolutions. Therefore to produce any given value of magnetic flux through a given magnetic circuit, a certain number of ampere turns of wire are required. With a sounder of the pattern described later, about 200 ampere turns are required to work the instrument satisfactorily. This may be provided by a single turn of wire upon each limb of the electromagnet, if a current of 100 amperes is provided. With one ampere 100 turns upon each limb would be needed, whilst with 100 m.a. 1000 turns would be necessary.

From this fact one or two very useful rules may be deduced. One is that the maximum effect is produced by any given type of apparatus when it is wound to a resist-

ance equal to the resistance of the rest of the circuit. The assumption which is made in this statement is that the windings occupy precisely the same space and that the wire is of the same material but of different gauge in the two instances. The relation is a trifle more complex when the thickness of the insulating covering upon the wire is taken into account, but the approximate rules which will be indicated are sufficiently near to the true results to be of considerable value.

The length of wire, and hence the number of turns of wire, which can be wound upon a bobbin of given dimensions is inversely proportional to the square of the total diameter of the wire. Thus

$$l_1 : l_2 :: (d_2)^2 : (d_1)^2$$

also

$$n_1 : n_2 :: (d_2)^2 : (d_1)^2$$

where l_1 and l_2, d_1 and d_2, n_1 and n_2 represent respectively the lengths, diameters, and number of turns of wire in each case.

But the relative resistances of the windings R_1 and R_2 in the two cases may be expressed thus :—

$$R_1 : R_2 :: l_1 \times (d_2)^2 : l_2 \times (d_1)^3$$

Substituting for l_1 and l_2 the relative values in terms of the diameter of the wire which can be wound upon the bobbin,

$$R_1 : R_2 :: (d_2)^2 \times (d_2)^2 : (d_1)^2 \times (d_1)^2$$

i. e.

$$R_1 : R_2 :: d_2^4 : d_1^4$$

but

$$n_1^2 : n_2^2 :: d_2^4 : d_1^4$$

$$\therefore n_1 : n_2 :: \sqrt{R_2} : \sqrt{R_1}$$

The last relation states that the number of turns of wire wound upon an electromagnet, and hence its figure of merit, is inversely proportional to the square root of the resistance of the windings.

The application of these principles may best be shown by a series of numerical examples.

Example 1.—The coils of a trembler bell (50$^{\omega}$ per coil) can be joined up in series or in parallel. Which method is preferable when the bell is directly connected to two cells in series, having an E.M.F. of 1^{v} and an internal resistance of 5$^{\omega}$ per cell?

The magnetic effects, M_1 and M_2, are proportional to the amperes turns ($A \times T$) in each case.

$$M_1 : M_2 :: A_1 \times T : A_2 \times T.$$

$$\text{In series, current} = \frac{2}{100 + 10} = \cdot 0182 \text{ amperes}$$

$$\text{In parallel, current} = \frac{2}{25 \times 10} = \cdot 057 \text{ amperes.}$$

The current in each coil in the latter case is ·0285 amp. since they are in parallel.

$$\therefore M_1 : M_2 :: \cdot 0182 \times T : \cdot 0285 \times T.$$
$$i.e.\ M_1 : M_2 :: \cdot 0182 : \cdot 0285.$$

Hence the coils should be placed in parallel.

Example 2.—An electromagnet is wound with two equal wires each having a resistance of 10ω, and is connected to a battery having an E.M.F. of 20ω, and an internal resistance of 10ω. Should the coils be connected in parallel or in series?

$$\text{In series, current} = \frac{20}{20 + 10} = \frac{2}{3} \text{ amp.}$$

$$\text{In parallel, current} = \frac{20}{5 + 10} = \frac{4}{3} \text{ amp.}$$

i.e. $\frac{2}{3}$ amp. in each wire.

$$\therefore M_1 : M_2 :: \tfrac{2}{3} : \tfrac{2}{3}.$$

The magnetic effects are equal in the two cases. Since the internal resistance of the battery is likely to rise series is preferable. Also the value of the current in the first case is half that in the second and the energy expended is also half as much, which again points to series as the arrangement to be preferred.

Example 3.—An electromagnet is wound with wire having a diameter of 20 mils to a resistance of 320ω. With what diameter of wire must it be re-wound in order that its resistance may be 20ω?

$$R_2 : R_1 :: d_1^4 : d_2^4.$$
$$i.e.\ 20 : 320 :: 20^4 : d_2^4.$$

$$\therefore d_2^4 = \frac{320 \times 20^4}{20} \text{ mils}$$

$$d_2^2 = \sqrt{16 \times 20^4} \text{ mils}$$
$$= 1600 \text{ mils}$$
$$d_2 = 40 \text{ mils.}$$

Example 4.—An instrument wound to a resistance of 1000$^{\omega}$ requires a current of 7 m.a. to satisfactorily work it. What current will be required to produce the same effect if it is re-wound to a resistance of 100$^{\omega}$?

$$\sqrt{R_2} : \sqrt{R_1} :: n_1 : n_2$$
$$\sqrt{100} : \sqrt{1000} :: n_1 : n_2$$
$$i.e. \quad 10 : 31{\cdot}62 :: n_1 : n_2$$

Since the effects are equal,

$$n_2 \times {\cdot}007 = n_1 \times C.$$
$$i.e.\ 10 \times {\cdot}007 = 31{\cdot}62 \times C.$$
$$\therefore C = \frac{{\cdot}007 \times 31{\cdot}62}{10} = 22 \text{ m.a. approx.}$$

Example 5.—Two electromagnets of precisely equal dimensions are wound with the same volume of wire, but the first is wound with 14 mils wire, and the second with 4·5 mils wire. What current will be needed to produce the same effect with the second electromagnet that 200 m.a. produces with the first?

$$d_2^2 : d_1^2 :: n_1 : n_2$$
$$i.e.\ 14^2 : 4{\cdot}5^2 :: n_1 : n_2$$

Since the effects are equal.

$$n_1 \times {\cdot}2 = n_2 \times C$$
$$i.e.\ 14^2 \times {\cdot}2 = 4{\cdot}5^2 \times C$$
$$\therefore C = \frac{{\cdot}2 \times 4{\cdot}5^2}{14^2} = 20{\cdot}7 \text{ m.a. approx.}$$

Example 6.—How would you join up sixty cells, each having an E.M.F. of 2 volts and an internal resistance of 4$^{\omega}$ per cell, to an electromagnet having a resistance of 15$^{\omega}$ in order to produce the largest possible effect with the means at disposal?

This is only another way of setting the type of question shown on page 49, since the effect is greatest when the current is greatest.

$$n = \sqrt{\frac{N \times R}{r}}$$

$$n = \sqrt{\frac{60 \times 15}{4}} = 15 \text{ cells in series,}$$

i. e. 4 rows in parallel, each row consisting of 15 cells in series—

$$\text{Current} = \frac{30}{15 + \frac{15 \times 4}{4}} = 1 \text{ ampere.}$$

Example 7.—Seventeen cells E.M.F. ·96 volt and 4Ω internal resistance per cell are used to work a circuit having a resistance of 132Ω, of which 36Ω is the resistance of the sounder. If the sounder is re-wound to a resistance of 144Ω what economy in battery power will result?

$$\text{with } 36\Omega \text{ sounder, current} = \frac{17 \times \cdot 96}{17 \times 4 + 132} = 82 \text{ m.a. approx.}$$

$$\sqrt{144} : \sqrt{36} :: 82 : C.$$

$$\therefore \text{ current required with } 144\Omega \text{ sounder} = \frac{6 \times 82}{12} = 41 \text{ m.a.}$$

$$\text{Resistance of circuit} = 96 + 144 = 240\Omega$$

$$\therefore \text{ number of cells} = \frac{240}{\frac{\cdot 96}{\cdot 041} - 4} = 13 \text{ cells.}$$

Hence three cells are saved.

CHAPTER III

GALVANOMETERS, RESISTANCE COILS, AND SHUNTS.

GALVANOMETERS.

THE value of an electric current is defined in terms of the magnetic field which it produces under certain conditions. A current must be measured indirectly, that is to say, in terms of the effects to which it gives rise. One of its most important effects is the production of a magnetic field, and it is upon this effect that all the instruments termed galvanometers depend. A galvanometer may be defined as an instrument used for the purpose of indicating, comparing, or measuring an electric current by means of the magnetic field due to the current in its coils.

The magnetic field round a current-conveying wire is strictly proportional to the value of the current flowing in the wire, and its direction depends upon the direction of the current producing it. If the relative values of the magnetic field at a given point produced by two successive currents in a particular conductor or series of conductors can be ascertained then the values of the two currents producing those magnetic fields can be ascertained.

The underlying principle in all galvanometers (with the exception of the D'Arsonval types) is the comparison of the value of the magnetic field produced by a current in the coils with that due to the earth. Having laid down this principle, the consideration of the details by which the object, viz. the measurement of an electric current, is attained will naturally follow.

A single loop of wire traversed by an electric current was illustrated in Fig. 2. The circles with their accompanying arrows indicate the position and direction of the lines of force due to the current traversing the loop in the

direction shown. Let this single turn of wire be placed in such a position that the earth's lines of force pass from *A* to *B*, or in other words, place it magnetically North and South. The coil is then said to lie in the magnetic meridian. A freely suspended compass needle points to the magnetic North and South, and if hung from the centre of the turn of wire, will lie along the imaginary straight line joining *A* and *B*. The tendency of this field is clearly to cause the magnetic needle to lie along it, or in other words, to take up a position with its North and South poles respectively East and West, or respectively West and East, according to the direction of the current. Were the earth's field absent this result would of course occur, but when the two effects are simultaneously present it is obvious that the needle will take up a position somewhere between the two positions. The actual position depends entirely upon the relative strengths of the two fields.

If the two fields are equal in magnitude the needle will take up a position midway between the North and South position, and the East and West position. The needle will, in fact, have been deflected through an angle of 45° from the normal, or North and South position. The position of a deflected needle is always defined by the angle which it makes with the normal position. In the present case it is, as already stated, termed a deflection of 45°.

The value of the magnetic field due to the earth may be considered to have a constant value during any particular set of measurements. This field is the one chosen for the purpose of making comparisons, and in the case cited it is obvious that the field due to the current and that due to earth are equal in value. If, however, the earth's field is greater than that of the current, the needle will lie more in the direction of the earth's field (N. and S.) than in the direction of the current's field (E. and W.). In other words, the deflection will be less than 45°, whereas it would be more than 45° if the current's field were greater than the earth's. Unfortunately the value of the magnetic field is not proportional to the angle of the deflection produced, but to the tangent of that angle. The reason for this fact lies in the different leverage which the magnetic fields have upon the needle in different positions. Con-

sider first the case in which the needle lies in its normal North and South position. The field due to the earth holds the needle in this position by a pull in the direction of its length. If, now, a small current be caused to flow through the coil, the field due to it acts directly at right angles to the needle. The current's field is now in the stronger position. As the needle deflects still further, the leverage of the earth's field is increased and that of the current's reduced until, when 45° is reached, both forces are pulling at the same angle to the needle. This is, of course, the case where the two fields are equal. As the deflection increases beyond 45° the earth gets continuously more and more leverage, and current less and less. Obviously, therefore, the increase in the value of the current's field required to produce a given increment of deflection rises from a minimum at 0° to a maximum at 90°. The position 90° cannot, however, be reached since the extreme tendency of the current's field is to place the needle East and West. This is opposed by the pull of the earth's field at right angles, and a position is therefore taken up which is less than 90°, although it is probable that the difference between the actual deflection and 90° cannot easily be perceived.

Attention has previously been drawn to the fact that magnetic fields cannot cross one another. The addition of a second magnetic field whose normal direction is at right angles to that of the first has the effect of altering the direction of both. The direction of the combined or new field is dependent upon their relative values. If they are equal, the direction is 45° from the position of either of them when considered alone. It is along this direction of the modified field that the compass needle sets itself. A very little consideration will show that these statements are in entire harmony with those previously made in regard to the position which a freely suspended compass needle will take up, when subjected to the action of two magnetic fields, whose normal directions are at right angles to each other.

The value of the current in a wire is strictly proportional to the magnetic field produced, and when this field is arranged to act at right angles to a constant magnetic field, its value at any particular point is proportional to the

tangent of the angle of deflection. The current is therefore proportional to the tangent of the angle of deflection.

The tangent law is subject to certain definite conditions, and unless these are carefully observed, serious errors are brought in. If the magnetic needle were infinitely small, an utterly impossible condition, the shape of the conductor might take any form one cared to choose. The infinitely small needle would indicate the direction of the resultant magnetic field at the point at which it was placed. If a long compass needle is employed it is obvious that the values of the magnetic fields are not always compared at the same point. The position of the needle with respect to the conductor or coil of wire varies with each different deflection produced. The needle moves in fact further and further away from the conductor, as the deflection is increased.

Tangent Galvanometer.

A tangent galvanometer consists essentially of a circular coil of wire, the diameter of which is large in comparison with the length of the magnetic needle suspended or pivoted at its centre. There are two corrections which have to be applied if absolute accuracy is desired. The first one may be entirely eliminated by making the depth of the windings bear to their width the ratio of $\sqrt{3} : \sqrt{2}$. The second correction cannot be so readily eliminated. It depends upon three factors, viz. the mean radius of the coil, the length of the needle, and the angle of deflection. The error is reduced to a small value by making the length of the needle one-tenth of the diameter of the coil. When the angle of deflection is 26° 34′ the correction vanishes, at 45° it amounts to nearly 1% and rises to a maximum of 3% at or very near 90°. The correction can be reduced to the order of $\frac{1}{100}$ of 1% by adopting the form of galvanometer devized by Helmholtz (Fig. 22). Two equal and parallel coils are employed with the needle lying midway between the two coils in the line joining their centres. The distance from the centre of either coil to the needle is made equal to half the radius of either coil.

It has already been shown that the current through a

tangent galvanometer is directly proportional to the tangent of the angle of deflection. In using a galvanometer, the scale of which is divided into degrees, constant reference to a table of tangents is necessary. This may be entirely avoided by dividing the scale into divisions proportional to the tangents of the angles of deflection. When this is done the value of any current is directly proportional to the number of divisions indicated by the needle or pointer. The construction of such a scale is a matter of the simplest description. A line is drawn at right angles to the line joining the zero of the scale and its centre. Upon this line on either side of zero a number of divisions, equal in length, are marked off. Straight lines are drawn connecting the divisions and the centre of the circle (Fig. 23). The numbers opposite the divisions upon the circle are then proportional to the tangents of the angles of deflection.

FIG. 22.—Helmholtz or Gaugain galvanometer.

TANGENT OF AN ANGLE.

In order to ascertain the value of the tangent of any particular angle, that angle should be marked off from *A O* along the quarter circle *O C* (Fig. 23). A line is then drawn connecting *A* and *O B* through the point upon the quarter-circle. The tangent of the angle is equal to the length from *O* to the point of intersection along *O B*, divided by the length of the radius of the circle. This number has only one value for any given angle, but it will be obvious that the larger the circle the greater is the accuracy with which the measurements may be obtained.

In Fig. 23 the radius of the circle is one inch, and the divisions are one-eighths of an inch, therefore the tangent of any angle drawn from *A O* is equal to the length in inches of the line from *O* to the point of intersection. The tangent of 0° is 0, since the length along *O B* for angle of 0° is 0. The tangent of 45° is seen to be eight one-eighths of one inch, *i.e.* one inch. Its tangent is therefore 1. In the case of 30° it will be seen that the intersection occurs just after $\frac{4}{8}$-inch, and making a guess at the point one would say it was about half-way between $\frac{4}{8}$ and $\frac{5}{8}$, *i.e.* $\frac{4}{8} + \frac{1}{16} = \frac{9}{16}$-inch. According to this guess its tangent is then $\frac{9}{16}$ or ·56 approximately. Its actual value is $\frac{1}{\sqrt{3}}$ or ·57735. The tangent of 60° is by

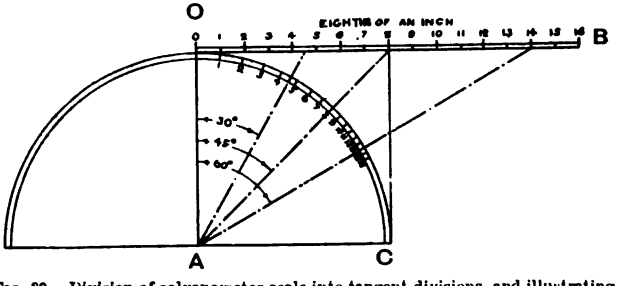

Fig. 23.—Division of galvanometer scale into tangent divisions, and illustrating the values of tan 0°, tan 30°, tan 45°, tan 60°.

the same rough and ready process found to be $\frac{14}{8}$ or 1·75. Its actual value is $\sqrt{3}$ or 1·73205. It will be noticed that tan 60° is exactly three times as large as tan 30°, and this fact may readily be verified by using a pair of dividers upon Fig. 23. From *O* to 14 is exactly three times the distance from *O* to the point marked 30°. The tangent of 90° is infinity since the lines *A C* and *O B*, being parallel, never meet. *A O* is of finite length and *O B* infinite.

Having made clear the actual values of the tangents of the various angles it is an easy matter to show the relative values of the divisions. For the purpose of simplifying the previous calculations the divisions bore a simple and direct relation to the radius of the circle. This is by no means essential. The length of a division upon the line *O B* may

be of any chosen value so long as all the divisions are of the same length.

The tangents of the angles of deflection are in each case the particular length marked off along $O B$, divided by the radius of the circle. The radius of the circle is the same in each case, therefore the tangents of the angles of deflection are directly proportional to the lengths marked off from O along $O B$. These lengths are, however, divided into equal divisions, consequently the divisions marked off along $O B$ are proportional to the tangents of the angles, and the current producing any deflection is therefore directly proportional to the number of divisions on the circle indicated by the needle or pointer.

Absolute Galvanometer.

Knowing the dimensions of a tangent galvanometer and the value of the horizontal component of the earth's magnetic field the value of a current producing any particular deflection can be calculated. The determination of the earth's field is readily accomplished by observation of the time of oscillation of a freely suspended bar-magnet, and by ascertaining the angle through which a compass needle is deflected by it at some particular distance. The dimensions and weight of the magnet also enter into the calculation, but each of these quantities is expressed in the fundamental units of length, mass, and time. Since there is no comparison with an existing standard magnetic field, such a determination is termed an "absolute" one. As stated above, the value of a current through a carefully designed tangent galvanometer can be calculated from the deflection, value of the earth's field and the dimensions of the coil. The experiment would be termed an "absolute" determination, since the value of the current is ascertained without reference to existing standards of current.

It has also been pointed out that the simple tangent law does not hold under certain circumstances, and all these corrections have to be most carefully allowed for. Needless to say, a controlling magnet is not used upon galvanometers designed for absolute measurements. An absolute galvanometer may be therefore defined as one in which all the dimensions are known with the utmost accuracy. It is frequently of the tangent type.

P.O. Tangent Galvanometer.

The general appearance of the Post Office pattern of tangent galvanometer is illustrated in Fig. 24. The base, frame, and needle box are all made of brass which is well lacquered. The controlling magnet and its stalk

Fig. 24.—P.O. Tangent galvanometer.

are shown by the side of the instrument. The part of the stalk shown upon the left side of the flange fits into the holder at the top of the ring, and is clamped by the thumb-screw. Raising or lowering the magnet upon its stalk may therefore be accomplished without fear of an accidental twist. The windings are $\frac{11}{32}$ inch broad, 1 inch deep, and

have a mean diameter of $6\frac{15}{16}$ inches (diameter of inmost layer $5\frac{15}{16}$ inches, and of outer layer $7\frac{15}{16}$ inches). A set of shunts is fixed upon the base, together with the terminals and the short-circuiting key.

The magnetic needle, provided with a cap of agate in the centre, is $\frac{7}{8}$ inch in length, and is pivoted upon an upstanding steel point in the centre of the brass box. To the needle, at right angles, is secured a light aluminium pointer, of sufficient length (5 inches) to reach over the

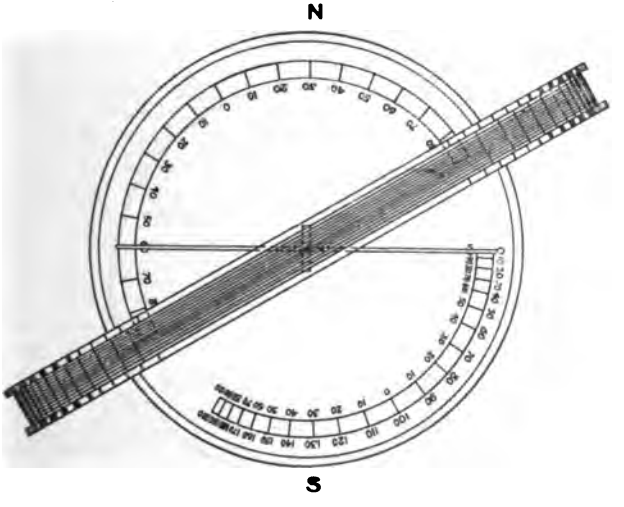

FIG. 25.—Sketch scale.

marked scale. If the pointer were in a straight line with the needle much of the scale would fall beneath the shadow of the coil, and would therefore be quite unreadable. A piece of looking-glass is fixed close to the scale in order that the deflections may be accurately read. Since the pointer is necessarily raised above the scale, a particular deflection could be read as several different values dependent upon the position of the eye. This parallax error, as it is termed, is entirely obviated by the mirror. When the pointer and its image in the mirror coincide the eye is directly above the needle. The pointer is composed of

aluminium because that metal possesses the twofold advantage of being light and non-magnetic.

A tangent galvanometer is not required for ascertaining the *direction* of a current, since a far simpler instrument serves this purpose equally well. By twisting the coil of the galvanometer through an angle of 60°, a very greatly extended range is obtained. The lower half of the scale (Fig. 25) is marked in degrees, whilst the top side of the upper half is marked in divisions representing equal currents. The scale is prepared upon both sides of the ordinary zero in the same manner as in the case of the ordinary patterns. It will be noted that the divisions are

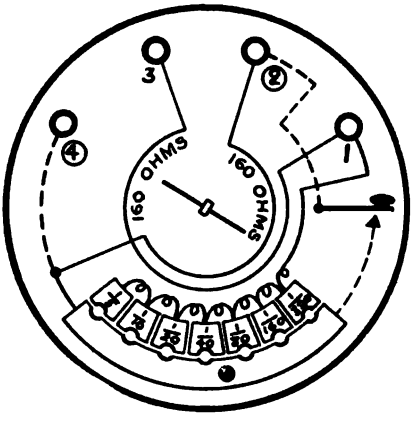

FIG. 26.—Connections of P.O. tangent galvanometer.

largest and most open at the centre of the scale. This means that deflections near to 100 can be read with very great accuracy. As a matter of fact the most accurate reading is obtained at 110 divisions. For deflections of less than 30° from the skew zero the skew scale has no advantage over the ordinary pattern, but for deflections larger than this the skew scale is distinctly beneficial. The divisions marked upon the bottom side of the upper half of the scale are used in connection with the battery testing instrument (*q. v.*).

The connections of the instrument are shown in Fig. 26.

A current entering at 4-circle passes through one coil of the galvanometer to 2-circle, which is usually connected by a brass strap to 3 and through the second coil to terminal 1. The depression of the key connects a short length of copper wire across the 2-circle 4-circle coil, or in other words "short-circuits" it. Each coil consists of 700 turns of silk-covered wire having a resistance of 160$^{\omega}$, *i. e.* 1400 turns and 320$^{\omega}$ with the coils in series. The values of the shunts and their resistances are set forth on page 115.

Differential Winding.

It will be noticed that there are two coils wound upon the P.O. tangent galvanometer, the 4-circle 2-circle coil being one, and the 3-1 coil the other. These two coils are equal in resistance, length, and position with respect to the needle. A current of any particular value would therefore produce the same deflection in traversing the 4-circle 2-circle coil as in traversing the 3-1 coil. When the current traverses both coils in the direction 4-circle to 1 the effect upon the needle is doubled. If, however, the terminals 4-circle and 1 are connected together and the positive pole of a battery is connected to them whilst its negative pole is connected to 3 and 2-circle connected together, no deflection will be produced. The current in each coil will have the same value since their resistances are equal. The current flowing from 4-circle to 2-circle will, however, tend to generate a magnetic field opposite in direction to that which the current flowing from 3 to 1 tends to produce. Since each coil has the same current flowing and its length and distance from the needle is the same, no effect upon the needle can be produced. It is quite impossible for two magnetic fields of opposite direction to simultaneously exist in one place, hence no magnetic field whatever is generated by the arrangement described. Any type of galvanometer may be differentially wound, and therefore a differential galvanometer may be defined as a galvanometer having two windings of equal resistance and equal but opposite effect upon the magnetic needle, when the same value of current circulates in each coil in contrary directions.

Controlling Magnet.

The object of the controlling magnet is to vary the sensitiveness of the instrument. The value of any current indicated by the galvanometer depends directly upon the value of the horizontal component of the earth's magnetic field. If this value is large then a correspondingly large current is required to produce a given deflection. If the controlling magnet is placed with its North pole facing the North pole of the needle the value of the earth's field is reduced, whilst if it has its South pole opposite the North pole of the needle the value of the earth's field is correspondingly increased. It will be obvious that the sensitiveness of the instrument is reduced if the controlling magnet is so placed as to attract the needle backwards, from the deflection produced, towards zero. If, on the other hand, there is repulsion, then the sensitiveness is increased. The extent to which the sensitiveness is increased or reduced is dependent upon the proximity of the controlling magnet to the needle. The nearer they approach the greater is the effect produced.

The controlling magnet should always be placed parallel to the needle, *i. e.* it should lie in the magnetic meridian. Unless this condition is observed the needle of the galvanometer may not point to the zero of the scale. In practice the controlling magnet is invariably used to increase the sensitiveness of the galvanometer; its North pole therefore facing the magnetic North.

Number of Convolutions.

The sensitiveness of a tangent galvanometer is directly proportional to the number of turns of wire and inversely as the value of the earth's field and as the radius of the coil. Since the needle is one-tenth the diameter of the coil the diameter of the coil cannot be unduly reduced. The value of the earth's field may be regarded as constant at any one place, and the controlling magnet is employed for comparatively small adjustments. There still remains to be considered the number of turns or convolutions of wire. This may be made very large indeed, and an extremely small current may in this way be made to provide a comparatively strong magnetic field.

The magnetic field produced by a coil of wire is proportional to the current flowing in that coil multiplied by the number of turns of wire. Therefore one ampere flowing in one turn of wire will produce the same field as one milli-ampere flowing through 1000 turns of the same diameter. This fact will readily be accounted for when it is remembered that one turn of wire conveying a particular current produces a certain magnetic field at its centre. The addition of a second turn obviously adds its magnetic field, and a third ditto. This amounts to the fact previously stated. The general arrangement of field in such a case is shown in Fig. 27.

In order to obtain a large number of turns of wire as near to the needle as possible, the wire should be fine.

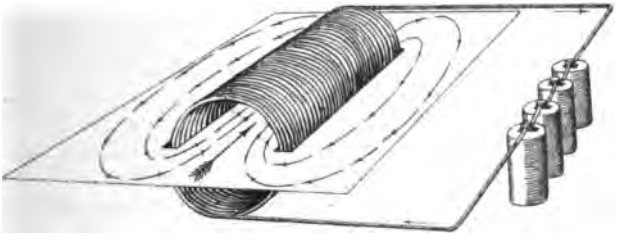

FIG. 27.—Illustrates magnetic field due to a coil of wire carrying a current.

This means a considerable amount of resistance, and thus it is that the term "high resistance galvanometer" has come to be synonymous with' 'highly sensitive galvanometer." It is interesting to note that if a particular instrument is re-wound with wire of different gauge, its sensitiveness is directly proportional to the square root of its resistance (see p. 77). For instance, if two galvanometers of equal dimensions each give 100 divisions deflection, and their resistances are respectively 900$^{\omega}$ and 9$^{\omega}$, the currents indicated in the two cases will be as $\sqrt{9} : \sqrt{900}$, *i. e.* as 3 is to 30, or as 1 : 10. The 9$^{\omega}$ galvanometer's 100 divisions therefore represent ten times as much current as the 900$^{\omega}$ galvanometer giving the same deflection.

HORIZONTAL GALVANOMETER.

The most sensitive form of galvanometer in common use

in the Post Office is known as the horizontal galvanometer (Fig. 28). It is used in connection with the Wheatstone Bridge, and has the merit of portability. It is not, however, as sensitive as even the most primitive of reflecting galvanometers.

It consists of a coil of wire with a comparatively long magnetic needle pivoted at its centre. The pointer is fixed at right angles to the needle, and a corresponding counterpoise provided upon the opposite side of the needle. The whole of the moving parts can be raised and clamped at will by moving the projection outside the brass case, thus avoiding damage during the removal of the instrument from place to place. As in the case of the tangent galvanometer, a mirror is employed to obviate parallax error.

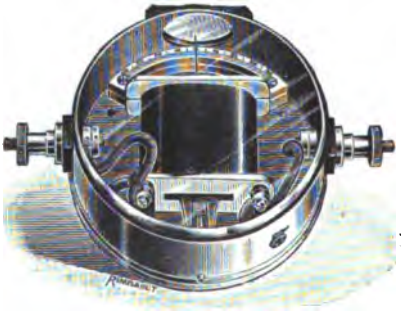

FIG. 28.—Horizontal galvanometer used in conjunction with the Wheatstone bridge.

The galvanometer should not be used for direct measurements of the value of a current, as the degrees are not proportional to the current. The relation would be a very complex one and would depend upon the moment of the needle, a somewhat uncertain and variable quantity. This could be met by calibration if urgently required, but, generally speaking, it should only be used for indicating the presence of a current.

REFLECTING GALVANOMETERS.

Galvanometers may be divided into two distinct classes, viz. reflecting galvanometers and pointer galvanometers. To the latter class belong all the galvanometers in use for purely telegraphic purposes. The former class comprises all galvanometers in which a mirror is affixed to the system of needles for indicating the deflection.

The original galvanometer of the reflecting type was

designed by Lord Kelvin, formerly Sir William Thomson, and consists of a circular coil of wire, in the centre of which is fixed a removable copper tube carrying a small circular mirror suspended from its centre by an extremely short length of silk. Upon the back of the mirror two or three short pieces of magnetized steel are fastened. The coil is placed in the magnetic meridian, and opposite it a lamp and scale for observing the deflection.

A beam of light is directed by a lens on to the mirror, which in its normal position reflects a circular beam of light on to the scale. When the mirror is deflected by the smallest amount the spot of light moves along the scale. This is roughly illustrated in Fig. 29, where it will be

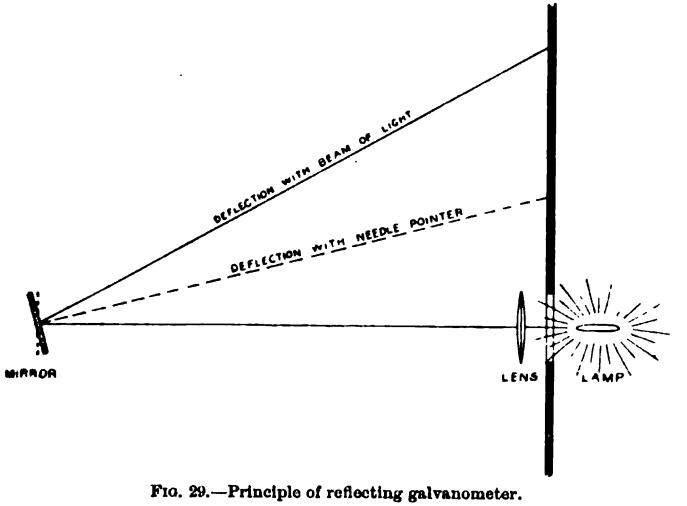

FIG. 29.—Principle of reflecting galvanometer.

observed that an almost imperceptible deflection of the mirror has produced a large alteration in the position of the spot of light upon the scale. The beam of light is practically a pointer of indefinite length, and by increasing the distance from the mirror to the scale, the sensitiveness of the arrangement may be greatly enhanced. The usual distance employed is a metre, *i. e.* rather more than a yard. If the scale divisions are equal, the conditions shown in

Fig. 23 are fulfilled, and the current may therefore be assumed to be proportional to the number of divisions passed over by the spot of light. If the angular deflection is extremely small the tangent law may be assumed to apply, since the corrections necessary when the dimensions widely differ from those laid down for an ordinary tangent galvanometer are extremely minute.

Since the angle at which the light strikes the mirror is equal to the angle at which it is reflected, the value of the deflection is doubled. In order to reflect the light of, say, a candle upon the ceiling, a mirror would have to be held at an angle of 45° to both the ceiling and the line joining the candle and mirror. Therefore it will be obvious that a deflection of 45° of the mirror would reflect a beam of light at 90°, or, as previously stated, twice the angle of deflection of the mirror. This fact introduces a very small correction which, for most practical purposes, is ignored. The actual error which is made is the assumption that half the tangent of the angle between the beam of light and its reflection is equal to the tangent of half the angle of deflection. In an absolute calculation the error amounts to rather less than $\frac{1}{3}\%$ for a 3° deflection of the mirror. In a comparative test the error would be far less.

Damping.

In the earlier forms of reflecting galvanometer the time taken for the needle to come to rest after being deflected was considerable, so that, in any given time, a comparatively small number of measurements could be made. This defect has been remedied in the more modern forms of instrument by various devices. The copper tube mentioned in the description of the original galvanometer was provided for the purpose of damping these vibrations, but it was only partially successful. The principle upon which it depends is that when a conductor moves across a magnetic field or when a magnetic field moves across a conductor an E.M.F. is generated. If the conductor be a complete circuit a current is generated, and this current produces a magnetic field in such a direction as to oppose the motion to which it owes its origin. The value of the induced E.M.F. and consequently of the current produced

depends upon the rapidity of the motion, therefore the more rapid the motion the greater is the retarding tendency or opposition (termed damping) to that motion. With reflecting galvanometers, the magnetic needles upon the back of the mirror carry with them a small magnetic field which is united with that of the earth. When the needle is deflected, its magnetic field cuts through the copper tube, and eddy currents, which oppose the rapid motion of the mirror, are generated in the tube.

FIG. 30.—Lamp and scale for use with reflecting galvanometers.

The opposition offered by the air contained in the restricted space of the copper tube to the rapid motion of the mirror through it also adds its damping effect. In certain forms of galvanometer the mirror has even been placed in oil.

A galvanometer in which the damping is very great is termed "*dead-beat*."

A lamp and scale is illustrated in Fig. 30. It may be

remarked that the circular spot of light thrown upon the scale is crossed by a fine vertical line. This vertical line is produced by a vertical scratch, or a fine wire upon the lens. Its object is to render the reading of the deflection easier and consequently more accurate. The dark line down the centre of the spot of light is adjusted by means of the controlling magnet to fall upon the zero of the scale and the value of any deflection is read as the number of

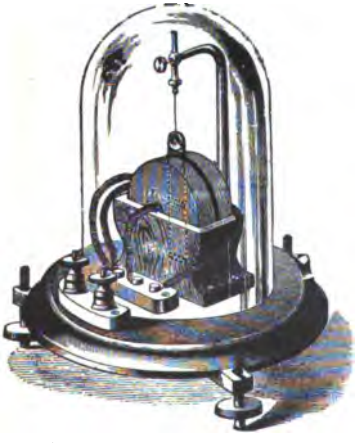

FIG. 31.—Simple form of Kelvin galvanometer.

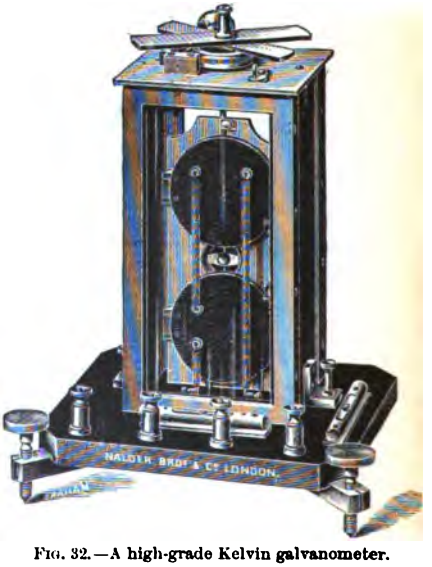

FIG. 32.—A high-grade Kelvin galvanometer.

the division upon which the line falls. In some cases a thin vertical slit of light is used instead of a circular beam, but this is considered scarcely so satisfactory as the round spot. It may also be remarked that the flame of the lamp should present its edge to the lens and not its breadth.

TYPES OF KELVIN GALVANOMETER.

A very useful, cheap, and easily-constructed type of Kelvin galvanometer (Fig. 31) is shown side by side with one of its most highly-developed forms (Fig. 32). The

former consists of two coils of wire wound upon two circular bobbins placed parallel but with a small intervening space. The mirror is carried upon a broad mica vane to which are also attached three magnets, one in the centre and the other two respectively above and below the outer windings of the coil. This produces an astatic combination, so making the instrument more sensitive. The mica vane is for the purpose of rendering the instrument dead-beat. Its surface in turning is comparatively large, and the air offers considerable resistance to its sudden motion through it. This damping device is a very satisfactory one. The controlling magnet consists of a bar magnet laid upon the table at a suitable distance from it.

The other is a four-coil differential astatic galvanometer.

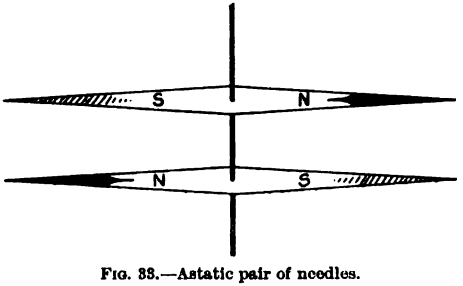

FIG. 33.—Astatic pair of needles.

The six needles are all mechanically connected to a wire which is in turn suspended by a silk fibre. The arrangement carries a series of mica vanes for producing damping. The final adjustment for differential use is made by a small auxiliary sliding coil, which can be moved nearer or further from one of the needles. In order to facilitate the adjustment of the time of swing of the needle, the instrument is provided with "scissors" magnet control.

ASTATIC NEEDLES AND SYSTEMS.

An astatic combination of needles may be employed in many types of galvanometer for the purpose of increasing the sensitiveness. In its simplest form it consists of two needles of equal length and equal pole strength, but with opposite poles facing each other, rigidly connected together

(Fig. 33). One needle swings in the centre of the galvanometer coil, whilst the other lies just above it. If the two needles are perfectly parallel, exactly equal in length, and exactly equal in pole strength, then the earth possesses absolutely no directive effect upon the combination of needles. In practice it is not possible to accurately secure the observance of all these conditions, but the effect of the earth's field can be reduced to an extremely small value. The field due to the current, on the other hand, produces its full effect upon the needle in the centre of the coil, and a lesser but by no means inconsiderable effect upon the needle above the coil. The direction of the field above the coil is opposite to that inside the coil, but since the polarity of the upper needle is opposite, both needles are urged in the same direction when a current flows through the coils of the instrument. It will therefore be obvious that the arrangement greatly increases the sensitiveness of the galvanometer.

The number of needles forming a combination may, and often does, exceed two. The qualification for an arrangement to be considered astatic is that the directive effect of the earth's field shall have been reduced to a minimum. Most reflecting galvanometers of the Kelvin type are fitted with an astatic combination of needles, usually three for each coil, *i. e.* one in the centre, one above the windings, and one below. Such a combination is very clearly shown in the case of the ballistic galvanometer illustrated in Fig. 35. In the case of the Kelvin type of galvanometer shown in Fig. 32 there are two coils with six needles.

The controlling magnet may be used to reduce the value of the earth's field still further, and so improve the sensitiveness of the instrument.

D'Arsonval Galvanometer.

The D'Arsonval galvanometer (Fig. 34) consists essentially of a coil of insulated copper wire wound upon a light copper frame with a mirror attached, suspended in an intense magnetic field by means of two thin conductors. The current is conducted through the coil by these fine suspension wires, which also serve to hold the coil in position. The direction of the magnetic field generated by

the current is at right angles to the plane of the coil, and the tendency is therefore for the coil to turn into such a position that its lines of force are in the same direction as the permanent magnetic field. This tendency is opposed by the torsion of the suspending wires, and the coil therefore takes up a position in which the tendency of the suspending wires to untwist is exactly equal and opposite to the tendency of the coil to still further deflect. It will therefore be obvious that the angle through which the coil turns is dependent upon the value of the current. The current may be assumed to be proportional to the deflection indicated upon an equally-divided scale. Where great accuracy is necessary, it is advisable to calibrate the galvanometer, although it is possible to theoretically arrive at the approximate value of the necessary correction.

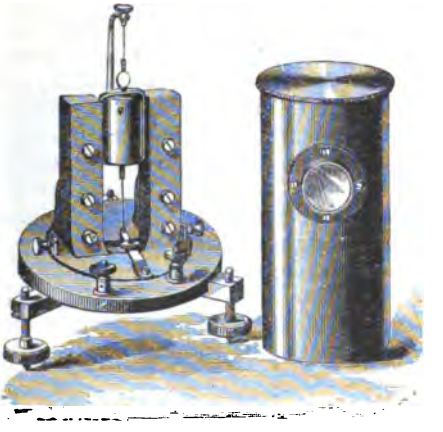

FIG. 34.—D'Arsonval galvanometer.

The intense magnetic field is produced by a large compound magnet of the horse-shoe type, and in order to avoid the reduction in its value which would take place if only the coil intervened between its poles, a large piece of soft iron is introduced. This piece of soft iron is supported from the back of the instrument and just leaves space for the coil to swing between it and the magnet. The resistance of the magnetic circuit is therefore greatly reduced, and the number of lines of force (or the flux as it is termed) is consequently greatly increased.

The light spring to which the lower suspension wire is attached serves to hold the coil in a central position and is adjustable by means of the screw above it. The top screw is chiefly used for bringing the spot of light to zero by removing any torsion upon the suspension.

The only point which now calls for special attention is the light copper frame upon which the coil is wound. This little device gives the instrument one of its most conspicuous advantages, viz. renders it dead-beat. The movement of the copper through the intense magnetic field entails the induction of currents in the mass of the copper. These currents oppose the motion to which they owe their origin, and since their value depends upon the rapidity of the motion of the coil, a very considerable opposition to sudden motion is experienced.

The great advantage of the D'Arsonval galvanometer over all others lies in the fact that it is not affected by external magnetic fields, and that it is so extremely dead-beat. It is, however, not quite so sensitive as some of the highest types of Kelvin galvanometer.

A special type of D'Arsonval galvanometer was formerly used by the Post Office for testing air-space cables. Instead of a mirror a pointer was fixed to the coil, and the effect of the change was to render the instrument anything but dead-beat. Further, the suspension was somewhat fragile, and breakages were not uncommon. These defects led to the design of the very sensitive horizontal galvanometer now employed (*vide* Chapter XXII).

It has, quite recently, been decided to adopt a galvanometer of the D'Arsonval type but with a pivoted coil to replace the instrument shown in Fig. 28.

Ballistic Galvanometer.

The ballistic galvanometer differs from other types of galvanometer in the kind of needle employed. It is used for measuring the quantities of electricity discharged by condensers or electromagnets, and not usually for measuring currents. It might therefore be more correctly termed a coulomb-meter. The needles are heavy and cylindrical, the object being to secure a weighty moving part and at the same time to reduce the friction caused by its movement as much as possible. With this object in view, the suspending silk is often made of considerable length. To give a correct indication it is essential that the whole of the discharge to be measured shall have passed through the instrument before the needle begins to move from its

position of rest. The quantity of electricity discharged through it is then proportional to the value of the swing produced. The period of time taken for the needle to swing from side to side is made as large as possible, and in this respect it is diametrically opposite to a dead-beat galvanometer.

One coil of the instrument (Fig. 35) has been swung open upon its hinge in order to show the construction of the needles. The central pair of needles consists of two tubes of steel with spherical extremities. The two open

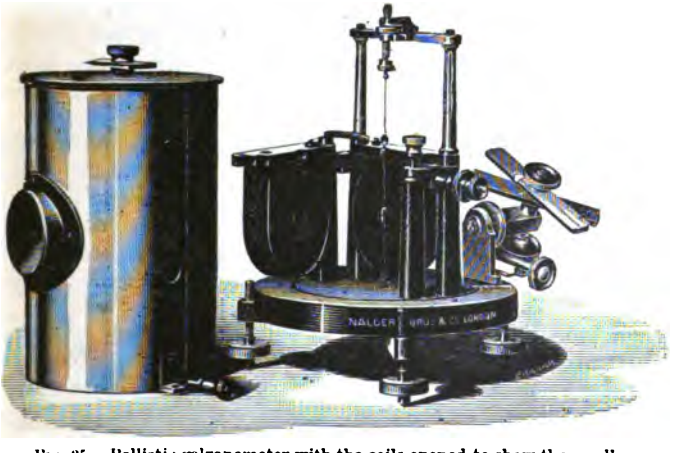

Fig. 35.—Ballistic galvanometer with the coils opened to show the needles.

ends of the tubes are brought together and both are split at each side, one side being made into a North pole and the other into a South; thus the arrangement corresponds to an ordinary magnetized needle, and in its normal position the slits are in a straight line passing through the centre of, and at right angles to, the plane of the coils. The needles at the top and at the bottom are similar to one of the needles at the centre, but their polarity is opposite since they are outside the coils. The extra needles which are mechanically connected together increase the sensitiveness of the instrument. The case carrying the small controlling magnet is shown at the side of the instrument. The large magnets at the back are used for the purpose of bringing

the needle to rest, instead of waiting until the vibration of the needle has died out after taking a reading. When the two magnets are placed one over the other, their effect upon the needle is *nil*, since they have opposite poles facing each other. Adjustment of their position is effected by the screws in connection with them.

Figures of Merit.

The figure of merit of a galvanometer is the value of the current required to produce a deflection of one division or one degree as the case may be. The smaller the figure of merit, the smaller is the minimum value of the current which the instrument will indicate. Sometimes the figure of merit is stated as the reciprocal of the current required to produce unit deflection, but this is not the practice of the Post Office. Yet another method of comparing the constants of galvanometers is to specify the value of the resistance in circuit with an E.M.F. of one volt to produce unit deflection. This is termed the "resistance constant," and is numerically identical with the value obtained for the figure of merit when defined as the reciprocal of the current required to produce unit deflection.

For the P.O. tangent galvanometer the figure of merit when adjusted to standard is $\frac{1}{80}$ m.a., the current required to produce a deflection of one division. In the case of a reflecting galvanometer, the current required to produce a deflection of one millimetre from the scale zero when the scale is one metre distant from the mirror is usually taken as the figure of merit.

Where the deflections of an instrument do not bear any simple ratio to the currents producing them, the deflection produced and the current required are stated. For instance, the figure of merit of a single-current galvanometer is 9·3 m.a., to give a deflection to the stop-pin. For the ordinary differential galvanometer it is 20 m.a. for a deflection of 40° to 50°. The limits provide a range of sensitiveness which should not be exceeded. For a horizontal galvanometer the figure of merit is ·048 m.a. for 25°.

Definition of Sensitiveness.

When the term "sensitive" is used in respect of

galvanometers generally, it means merely that the increase in the current required to perceptibly raise the deflection is small. It may be put in another way. Imagine that a current flowing through a galvanometer is producing a certain deflection and then imagine that the value of that current is increased or reduced by an extremely small fraction of its value. The galvanometer which would produce the largest alteration in deflection corresponding to the minute fractional change of current value would be considered the more sensitive. This is the accurate meaning of the term, but it is frequently employed as a substitute for "small figure of merit," or large resistance constant.

RESISTANCE COILS.

A set of resistance coils or a resistance box is perhaps one of the most useful and necessary adjuncts in electrical testing. These boxes contain coils of wire of definite resistance, which can be thrown into circuit or cut out at will. The wire forming the resistance coil is wound upon a bobbin in a special manner—the reason for which will receive consideration later—and is well insulated with one or two layers of silk covering wound spirally upon the conductor.

The coils are connected between a series of brass blocks cut to receive a circular peg between each block and its neighbour (Fig. 36). With all the plugs in position, the brass block forms a continuous conductor of negligible resistance between the two terminals. The removal of any plug inserts a resistance coil between the terminals of the instrument of the value marked near the two brass blocks. In the case illustrated (Fig. 36) the 2^{ω}, 3^{ω}, and 4^{ω} coils are in circuit, that is to say a resistance of 9^{ω} is introduced between the terminals. The 1^{ω} coil in this case is short-circuited by the plug.

The brass blocks are fitted upon a slab of ebonite, a material possessing very high insulating qualities. The brass blocks are recessed upon either side, beneath the plug holes, in order to provide facilities for cleaning the ebonite and removing all dust, dirt, or metallic filings, due to the continual twisting of the plugs in their holes.

The brass plugs usually take one of two forms—either a

turned plug of brass or a plug of brass with an ebonite handle. The latter is the preferable form on account of the superior grip which can be obtained upon it. It is a matter of considerable importance that the plugs should fit accurately and tightly, and that the contact surfaces should be kept bright and clean. Where accuracy is required, these points must receive very careful attention, for it will be obvious that even four bad contacts in series will produce a considerable amount of resistance which should not be present. Again, this resistance will vary with the

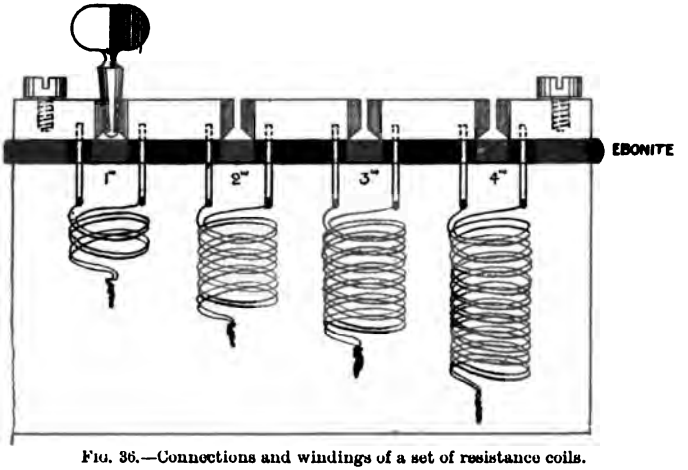

FIG. 36.—Connections and windings of a set of resistance coils.

manner in which the plug is inserted. A plug should be put in firmly with a twisting motion in order to ensure a good contact. Neglect of this simple and obvious precaution often produces somewhat serious errors. Upon the other hand, resistance boxes must be handled carefully, and the use of considerable force in putting in the plugs is strongly deprecated.

The values given to the coils usually take the following form: 1, 2, 3, 4; 10, 20, 30, 40; 100, 200, 300, 400, etc. The right-hand set of four coils, shown in Fig. 37, has the values 1^{ω}, 2^{ω}, 3^{ω}, and 4^{ω}, and it will therefore be seen that any resistance from 1^{ω} to 10^{ω} by gradations of 1^{ω} can be

thrown into circuit. This is termed a set of unit coils. The centre set of coils contains 1, 2, 3, 4 units and tens—and any resistance from 1ω to 110ω by gradations of one

Fig. 37.—Resistance coils.

ohm can thus be obtained. The large set upon the right contains a set of four "units" coils, four "tens" coils,

Fig. 38.—Retardation coils.

four "hundreds" coils, and four "thousands" coils, which thus provide for any integral resistance from 1ω to 11,110ω.

Two forms of resistance box employed in practical telegraphy are illustrated in Figs. 38 and 39. The former,

known as a set of "retardation coils," on account of the purpose to which it is put (see Chapter VII), has eight coils of the following resistances : 10ω, 20ω, 30ω, 40ω, 100ω, 200ω, 300ω, 400ω. This gives 10ω to 1100ω by gradations of 10ω.

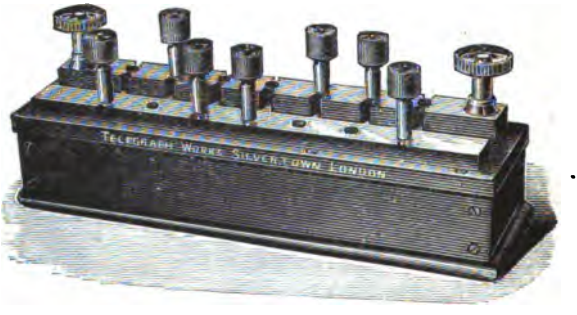

Fig. 39.—Condenser coils.

The second form used for a similar purpose is in contradistinction known as a set of "condenser coils." The resistance of its seven coils are respectively 50ω, 100ω, 200ω, 300ω, 400ω, 1000ω, and 2000ω, *i.e.* 50ω to 4050ω by gradations of 50ω. Both these sets of coils are used in cases where the absolute accuracy of the resistance is of very little consequence, and the form chosen is therefore simpler than those previously illustrated.

Fig. 40.—Single plug resistance coils.

Another type of resistance box, designed to avoid the resistance due to a number of plugs in series, is illustrated in Fig. 40. This form necessitates a resistance coil for each value of resistance. To obtain 1ω to 9ω by 1ω, nine coils are necessary, as against four coils to give 1ω to 10ω by the previous arrangement. The heavy central brass block forms one terminal, and the block marked 0 the other. A resistance of 1ω is connected between the blocks marked 0ω and 1ω, 1ω and 2ω, 2ω and 3ω, etc. The introduc-

tion of the peg at 1ω connects the 1ω coil and at 4ω the four coils between the 0ω, 1ω, 2ω, 3ω and 4ω blocks. For any particular resistance, therefore, there is only one plug needed. This presents a considerable advantage where great accuracy is required. The guaranteed accuracy of this particular type is ·02 per cent.

Shunts are usually arranged in this way, and a consideration of Fig. 26, after reading the later part of this chapter, will make this apparent.

Type of Wire to be used.

The material of which the wire for a resistance coil is composed is a matter of considerable importance. Copper wire is quite inadmissible on account of its large changes in resistance with changes of temperature. Again, where a large resistance is required, the quantity of wire necessary would render the coils very bulky, or extremely fine wire would have to be employed.

The wire chosen should have a very high resistivity and a small temperature variation of resistance. The wire should not oxidize, or, in fact, be subject to any change of its resistance through age. The three alloys which are most used are German silver, platinoid, and platinum silver. Their temperature variations of resistance are respectively ·044%, ·021%, and ·031% per degree Centigrade, as against the ·428% of copper. German silver is perhaps the oldest and most extensively employed material, whilst platinoid, manganin, and eureka, are coming into ever-increasing use. Platinum silver is very expensive and is only employed for important standards. It is known to age very little and to be subject to no oxidation, and has a small and very accurately known temperature variation of resistance.

The resistivities and temperature coefficients of copper and a few well-known and frequently used alloys* are given on page 110 for purposes of comparison.

* German silver is composed of 4 parts of copper, 2 of nickel and 1 of zinc. Manganin consists of 84 parts copper, 12 parts manganese and 4 parts nickel. Platinoid is composed of tungsten nickel, copper and zinc.

Material.	Resistivity, per cubic centimetre, in microhms.	Temperature coefficient % per degree C.
Annealed copper	1·69639	·428
German silver .	20 to 30	·044
Platinum silver .	25 to 30	·031
Platinoid . .	40	·021
Eureka . .	40	Nil
Manganin . .	42 to 46	Nil

All resistance coils are marked with the temperature at which they are correct, and this is usually made 15·5° C. or 60° F. In the case of very important standard coils the temperature variation is carefully determined, and a certificate as to this and the resistance of the coil is provided by the makers.

Gauge of Wire.

The gauge of the wire to be employed next requires consideration. Where cost and size are no object the gauge should be large, since this will give great accuracy of adjustment, and any rise of temperature due to the passage of a current through it will be reduced to the lowest possible value. Naturally a wire with a large surface will radiate any heat generated much faster than a smaller one, and its temperature will consequently be lower. In practice, however, the questions of cost and bulk are distinctly important, and therefore it is that the low resistance coils are made of a thick wire, whilst the high ones are composed of fine wire. If fine wire were used for the low resistance coils the length of wire necessary would be short, and consequently the accurate adjustment of the actual length required would be extremely fine, and therefore subject to considerable inaccuracy. Usually, too, the currents flowing through low resistances are larger than those flowing through high resistances, and upon this account also thick wire is desirable.

Rheostats.

A form of resistance box, termed a rheostat, used by the Post Office upon telegraph circuits is illustrated in Fig. 41.

It consists of two contact arms, each of which is capable of moving over a semicircle of contact points, and three separate resistance coils and plugs. The one set of studs is consecutively marked 0, 40, 80, 120, 160, 200, 240, 280, 320, 360, and 400, whilst the other half is similarly marked, but with values ten times as great, *i. e.* 400 to 4000. By means of the nearer arm any resistance up to 400Ω by gradations of 40Ω can be inserted. With the other any resistance from 400Ω to 4000Ω, by gradations of 400Ω, may be obtained. Using both arms, any resistance from 0 to 4400Ω

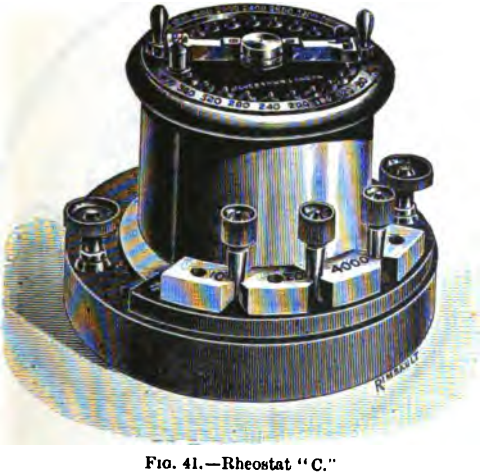

FIG. 41.—Rheostat "C."

by gradations of 40Ω may be obtained. On the base of the instrument three coils of 10Ω, 20Ω, and 4000Ω are provided, thus bringing up the maximum resistance obtainable to 8430Ω. The first two coils provide for gradations of 10Ω instead of 40Ω; for instance, 3370Ω would be provided by the 400Ω coil arm at 3000Ω, the 40Ω coil arm at 360, and the 10Ω coil plug out. 3380Ω would require the 20Ω coil, 3390Ω both 10Ω and 20Ω, whilst 3400Ω would be provided by moving the 40Ω coil arm to 400Ω and plugging up both the base coils. The 4000Ω coil is for use when the resistance required exceeds 4430Ω. The connections are shown in Fig. 42, and are so obvious as to require no comment.

There are at present three forms of rheostat in daily use in the Post Office, that illustrated in Fig. 41 being known as the rheostat "C." The "B" is somewhat shorter than the "C" type, and is wound with finer wire. It is never used upon circuits worked with bichromate batteries, or upon secondary cell worked circuits, on account of the heating which almost inevitably results.

The third, or "D" form, illustrated in Fig. 43, is now the standard pattern, and possesses the merits of greater

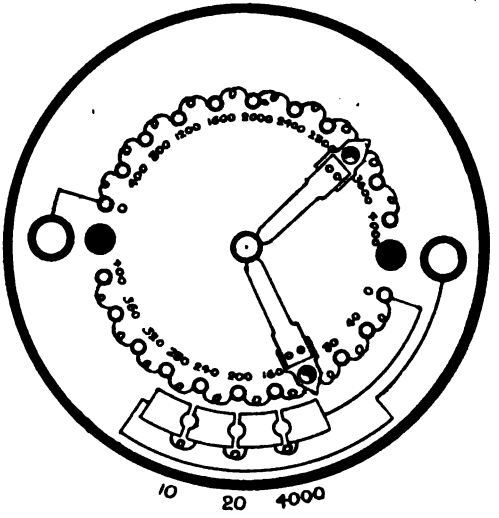

FIG. 42.—Connections of rheostat "C."

cheapness and superior efficiency of the contacts. The two radial arms each consist of strips of phosphor bronze, bent as shown, bearing down upon the circular brass contact blocks, between which the 40ω and 400ω coils are connected. In addition, 10ω, 20ω, and 4000ω plug coils are provided, as in the "B" and "C" types.

DOUBLE-WINDING.

All resistance coils are so wound as to have the smallest possible self-inductance. This is accomplished by doubling

the wire and winding it as indicated in Fig. 36. A current traversing the coil does not generate a magnetic field, and the coil has therefore no self-inductance. Moreover, magnets moved in the vicinity of the coils will not produce induced currents. In considering such instruments as Wheatstone bridges, it will be quite apparent that this special method of winding is essential.

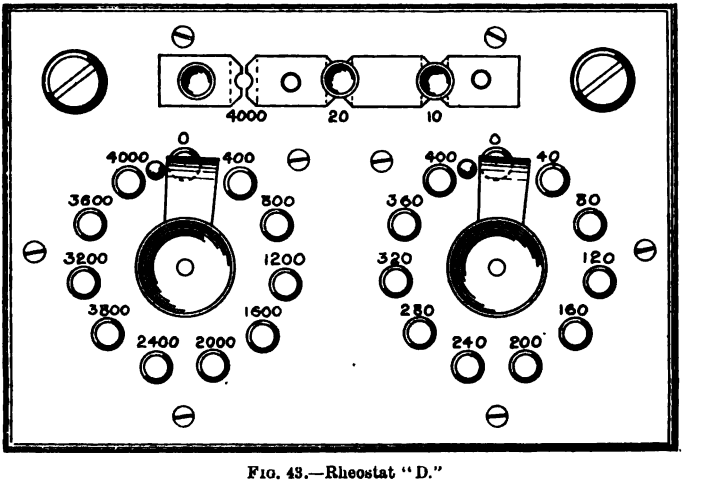

FIG. 43.—Rheostat "D."

GALVANOMETER SHUNTS.

The value of the current which can be measured by any particular galvanometer is distinctly limited. For instance, a Post Office tangent galvanometer will give a deflection of 200 divisions with a current of $2\frac{1}{2}$ m.a. If it is desired to measure a larger current, two courses are open, the one to re-wind the galvanometer with a proportionally smaller number of turns of wire, or to divert a large known portion of the current and to infer the value of the total current from a knowledge of the actual current shown upon the galvanometer and the proportion diverted. The former method has sometimes been employed and a plug switch provided by which any particular number of turns of wire could be joined up.

Principle.

The method of diverting a known proportion of the current through another path placed in parallel with the galvanometer is termed "shunting the galvanometer," and the resistance employed is, in this connection, termed a "shunt." The arrangement is shown in Fig. 44, where the galvanometer G has a shunt S connected across its terminals. The current entering the instrument divides between the galvanometer and the shunt in direct proportion to their conductances. If the resistances of the galvanometer and its shunt are equal, one half of the current flows through each path. The galvanometer therefore indicates $\frac{1}{2}$ of the current flowing through the whole arrangement. The

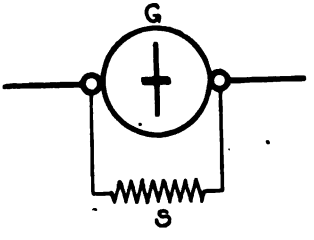

Fig. 44.—Shunted galvanometer.

current indicated upon the galvanometer must therefore be multiplied by 2, and 2 is accordingly termed the multiplying power of the shunt. The shunt is termed a $\frac{1}{2}$ shunt.

Let the resistance of the galvanometer under consideration be 90ω, and then determine the consequences following the use of various shunt resistances. It has already been shown that if the shunt were 90ω it would be termed a $\frac{1}{2}$ shunt, and have a multiplying power of 2. If now the shunt were 45ω, two-thirds of the total current would pass through the shunt and one-third through the galvanometer, therefore it would be a $\frac{1}{3}$ shunt.

The table on page 115 gives the particulars of nine different shunts which might be applied to the 90ω galvanometer, together with various facts derived therefrom :—

Resistance of galvanometer. (Ohms.)	Resistance of shunt. (Ohms.)	Proportion of the total current in the galvanometer.	Proportion of the total current in the shunt.	Name of shunt.	Multiplying power of shunt.
90	90	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	2
90	45	$\frac{1}{3}$	$\frac{2}{3}$	$\frac{1}{3}$	3
90	30	$\frac{1}{4}$	$\frac{3}{4}$	$\frac{1}{4}$	4
90	18	$\frac{1}{6}$	$\frac{5}{6}$	$\frac{1}{6}$	6
90	15	$\frac{1}{7}$	$\frac{6}{7}$	$\frac{1}{7}$	7
90	10	$\frac{1}{10}$	$\frac{9}{10}$	$\frac{1}{10}$	10
90	9	$\frac{1}{11}$	$\frac{10}{11}$	$\frac{1}{11}$	11
90	$4\frac{1}{2}$	$\frac{1}{21}$	$\frac{20}{21}$	$\frac{1}{21}$	21
90	2	$\frac{1}{46}$	$\frac{45}{46}$	$\frac{1}{46}$	46
90	1	$\frac{1}{91}$	$\frac{90}{91}$	$\frac{1}{91}$	91

The shunt takes its name from the fraction of the total current flowing through the galvanometer itself. If the 90$^{\omega}$ galvanometer unshunted gave a deflection of 20 divisions with 1·5 m.a. flowing through its coils, the value of 20 divisions with each of the shunts shown would be 1·5 m.a. multiplied by the multiplying power of the shunt, *e. g.* $\frac{1}{2}$ shunt (1·5 × 2) m.a.; $\frac{1}{3}$ shunt (1·5 × 3) m.a.; $\frac{1}{4}$ shunt (1·5 × 4) m.a.; etc.

From a consideration of the numerical examples given for this particular galvanometer, it will be observed that the following relations hold :—

$$\text{Multiplying power} = \frac{\text{Galvo. res.} + \text{Shunt res.}}{\text{Shunt res.}} \quad . \quad . \quad (1)$$

$$\text{Shunt res.} = \frac{\text{Galvo. res.}}{\text{Multiplying power} - 1} \quad . \quad . \quad . \quad (2)$$

Rule I. states that the multiplying power of a shunt is equal to the sum of the resistances of the galvanometer and the shunt divided by the resistance of the shunt. In the case of the 10$^{\omega}$ shunt to the 90$^{\omega}$ galvanometer its multiplying power is at once found to be :—

$$\frac{90 + 10}{10} = 10.$$

The second rule enables the resistance of the shunt necessary to reduce the current through the galvanometer

itself in any desired proportion to be ascertained. The shunt resistance required is equal to the galvanometer resistance divided by a number obtained by subtracting unity from the power of the shunt required. In the case of the 90ω galvanometer, if it is desired to apply a $\frac{1}{6}$ shunt its resistance must be :—

$$\frac{90}{6-1} = 18\omega.$$

Having established these rules the following numerical examples of their application should be clear.

Example 1.—A galvanometer of 320ω resistance having a constant of 80 divisions per milli-ampere is shunted by a resistance of $35\frac{5}{9}\omega$. What is the power of the shunt, and what is the constant of the shunted instrument?

$$\text{From (1) multiplying power} = \frac{320 + 35\frac{5}{9}}{35\frac{5}{9}}$$
$$= 10$$
$$\text{Constant shunted} = \tfrac{1}{8} \text{ m.a. per division.}$$

Example 2.—What resistance must be applied to a 320ω galvanometer in order to shunt it $\frac{1}{5}$, and what will be its constant if, when unshunted, 80 divisions represent 1 m.a.?

$$\text{From (2) shunt} = \frac{320}{5-1} = 80\omega$$

Unshunted 80 divisions = 1 m.a.
Shunted $\frac{1}{5}$,, ,, = 5 m.a.
or 16 ,, = 1 m.a.

It will be obvious that the application of a shunt to a galvanometer reduces the resistance of the instrument as a whole. The resistance is then equal to the product of the resistances of the galvanometer and shunt divided by their sum. Fortunately a much simpler relation holds in the case of a galvanometer and shunt. It is—

$$\text{The combined resistance} = \frac{\text{Resistance of Galvanometer}}{\text{Power of shunt}} \quad (3)$$

For instance, the combined resistance of the 320$^{\omega}$ galvanometer and shunt dealt with in the last example will be, according to this rule, $\frac{320}{5} = 64^{\omega}$, a result which may readily be verified.

Compensating Resistance.

The reduction in the resistance of a circuit containing a galvanometer, due to the application of a shunt, leads to an increased value of current through that circuit. The application of the $\frac{1}{5}$ shunt, therefore, would not reduce the value of the current from, say, 200 divisions to 40 divisions. If the resistance of the circuit, exclusive of the galvanometer, were absolutely nil the application of the shunt would not reduce the deflection at all. This fact led Kempe to design a special shunt box in which each shunt when applied also introduced a resistance in the main circuit, equivalent to the decrease produced by its application. This resistance was termed a compensating resistance, and in the case of a 320$^{\omega}$ galvanometer with $\frac{1}{5}$ shunt would be $320 - \frac{320}{5}$ $= 256^{\omega}$. The joint resistance added to the compensating resistance is, of course, 320$^{\omega}$, so that the application of the shunt would not alter the resistance of the apparatus as a whole.

The device has not, however, found favour in practice for two reasons, firstly, its cost, and secondly, that in the majority of cases the resistance of the galvanometer or of the galvanometer and shunt is but a small fraction of the resistance of the circuit as a whole. In the few cases where this is not the case the calculation of the effect of the diminished resistance is comparatively simple. To take a practical case occurring in every-day telegraph work. The current flowing through a duplex circuit may be measured by inserting a tangent galvanometer at the test box whilst the keys are at rest. The $\frac{1}{10}$ shunt is applied which reduces the galvanometer resistance to 32$^{\omega}$ and a deflection of, say, 54 divisions is obtained. To be strictly accurate, the fact that the circuit resistance, say 1200$^{\omega}$, has been increased by $2\frac{2}{3}\%$ owing to the introduction of the galvanometer should be allowed for in calculating the current in the circuit from the measurement. The value

observed should be increased in the same percentage, but it should be noted that the circuit resistance in this case must include the batteries. In this instance the compensating resistance would be highly objectionable since the resistance introduced into the circuit would be 320ω instead of 32ω, and the increase in the circuit resistance would therefore amount to $26\frac{2}{3}\%$. If the current indicated under these circumstances were 20 m.a. the value of the current through the circuit working normally would be $25\frac{1}{3}$ m.a.

In the case of measuring very high resistances the correction necessary is usually so small as to be negligible. This is the case with the testing set described in Chapter XX, Part IV.

P.O. Tangent Galvanometer Shunts.

It will now be possible to deal with the shunts in connection with the P.O. tangent galvanometer. The shunts provided are $\frac{1}{5}$, $\frac{1}{10}$, $\frac{1}{20}$, $\frac{1}{40}$, $\frac{1}{80}$, $\frac{1}{160}$, and $\frac{1}{320}$, and they are connected from terminal 4-circle to terminal 1 by the introduction of a plug between the main brass block and the particular shunt block chosen. Instead of providing a separate coil of the total value necessary for each shunt each coil merely adds the additional resistance required to bring the total to the specified value. In the galvanometer illustrated in Fig. 26, the $\frac{1}{5}$ shunt is the lowest power and has therefore the highest resistance, viz. 80ω. This is the sum of all the coils in series added together. The $\frac{1}{10}$ shunt requires only 35·56, which is the sum of all the coils on the right. The actual resistance of the coil between the $\frac{1}{5}$ and $\frac{1}{10}$ block is therefore 44·44ω.

The constant of a properly adjusted P.O. tangent galvanometer is 80 divisions per milli-ampere. The angle of maximum sensitiveness has been stated to be 110 divisions, and therefore, in any given case, the shunt which will make the deflection nearest to 110 divisions should be employed. The following table gives all the necessary particulars in regard to the instrument:—

P.O. TANGENT GALVANOMETER.

Resistance of coils, 320ω.
Angle of maximum sensitiveness, 110 divisions.
Maximum deflection, 200 divisions.

Name of shunt.	Value of 1 division.	*Value of 110 divisions.*	Value of 200 divisions.	Resistance of shunt.	Combined resistance.	Compensating resistance.
Unshunted	$\frac{1}{200}$ m.a.	*1·375 m.a.*	2·5 m.a.	—	320ω	—
$\frac{1}{8}$	$\frac{1}{160}$,,	*6·875* ,,	12·5 ,,	80ω	64ω	256ω
$\frac{1}{10}$	$\frac{1}{80}$,,	*13·75* ,,	25 ,,	35·56ω	32ω	288ω
$\frac{1}{20}$	$\frac{1}{40}$,,	*27·5* ,,	50 ,,	16·84ω	16ω	304ω
$\frac{1}{40}$	$\frac{1}{20}$,,	*55* ,,	100 ,,	8·205ω	8ω	312ω
$\frac{1}{80}$	1 ,,	*110* ,,	200 ,,	4·051ω	4ω	316ω
$\frac{1}{160}$	2 ,,	*220* ,,	400 ,,	2·013ω	2ω	318ω
$\frac{1}{320}$	4 ,,	*440* ,,	800 ,,	1·003ω	1ω	319ω

Shunts are very frequently employed in connection with reflecting galvanometers and usually three values are supplied, viz. $\frac{1}{10}$, $\frac{1}{100}$, and $\frac{1}{1000}$. Unfortunately many makers insist upon labelling these shunts with the fraction of the resistance of the galvanometer, *i.e.* $\frac{1}{9}$, $\frac{1}{99}$, and $\frac{1}{999}$. This fact occasionally leads to some confusion in the minds of students. Such a shunt box is illustrated in Fig. 45. The two terminals are connected to the galvanometer and the particular shunts are introduced by placing the plug between the central block and the particular shunt required. At the back is placed a small movable switch which, upon being moved downwards, short circuits the shunts altogether. The connections may be inferred from the detailed description of the tangent galvanometer shunts.

FIG. 45.—Galvanometer shunt box.

The following examples show a couple of problems which may arise in connection with shunts as applied to reflecting galvanometers.

Example 3.—A galvanometer of 950ω resistance shunted $\frac{1}{10}$ gives a deflection of 53 divisions. What must be the

resistance of the shunt applied to increase the deflection to 240 divisions?

Galvo. shunted $\frac{1}{10}$ gives 53 divisions.
$\therefore$ Galvo. unshunted gives 530 divisions.

Multiplying power of shunt to reduce 530 to 1 division
$= 530$
$\therefore$ „ „ „ „ „ increase 1 div. to 240 divs.
$= \frac{530}{240}$

$$\text{Shunt} = \frac{950}{\frac{530}{240} - 1}$$

$$= \frac{950}{290} = 786{\cdot}2^{\omega}.$$
$$240$$

Example 4.—If the constant of a galvanometer of 800$^{\omega}$ resistance is ·002 m.a. per division, what will be its constant when shunted by a resistance of 55$^{\omega}$?

$$\text{Multiplying power} = \frac{800 + 55}{55}$$

Unshunted. Value of 1 division = ·002 m.a.

Shunted. „ „ „ $= {\cdot}002 \times \frac{855}{55}$

$= {\cdot}03109$ m.a. approx.

Universal Shunt.

The arrangement of shunts, previously considered, possesses the very great disadvantage that each set must be specially designed for the particular resistance of galvanometer with which it is to be used. This defect has been met by the invention of the universal shunt by Ayrton and Mather. This shunt may be applied to any galvanometer, irrespective of its resistance, and still give equally accurate results. On page 115 it was stated that:—

$$\text{Multiplying power} = \frac{\text{Galvo. resistance} + \text{Shunt res.}}{\text{Shunt res.}}$$

If now the resistance of the galvanometer added to the shunt resistance could always have the same value, the multiplying power of the shunt would be the number resulting from the division of this constant resistance by the resistance of the shunt applied.

In the universal shunt a sub-divided resistance of 10,000$^{\omega}$ is connected directly across the terminals of the galvanometer, and a radial contact arm moves over the series of studs in connection with those sub-divisions. The arrangement is conventionally depicted in Fig. 46. When the arm is on the position marked 1 there is a resistance of 10,000$^{\omega}$ across the terminals of the galvanometer, and the multiplying power is therefore equal to $\frac{\text{Galvanometer} + 10{,}000^{\omega}}{10{,}000}$

This is called 1.

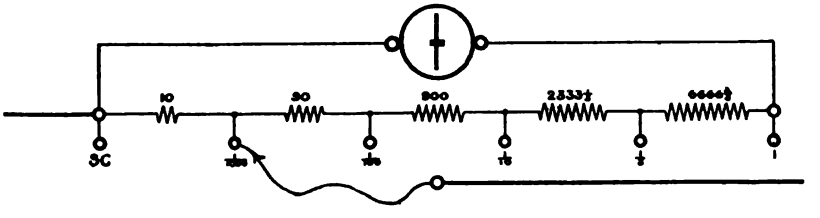

FIG. 46.—Principle of the universal shunt.

When the arm is moved to $\frac{1}{3}$ the resistance thrown into the circuit of the galvanometer is 6666·7$^{\omega}$, and across this is a resistance of $\frac{1}{3}$ of 10,000$^{\omega}$ = 3333·3$^{\omega}$. The multiplying power is therefore :—

$$\frac{(\text{Galvo.} + 6666{\cdot}7^{\omega}) + 3333{\cdot}3^{\omega}}{3333{\cdot}3^{\omega}}$$

$$i.e. \quad \frac{\text{Galvo.} + 10{,}000}{3333{\cdot}3}$$

This is precisely three times the multiplying power in the first case.

It will therefore be apparent that the value of the Galvanometer + Shunt is always the same no matter what position the arm may occupy. The multiplying power of any shunt is therefore its resistance divided into a constant

number. By the term shunt is meant the resistance from the left terminal of the instrument to the radial arm.

Hence—

$$\text{Multiplying power} = \frac{\text{Total res. of box}}{\text{Res. of shunt}}.$$

A very little consideration of the figures given upon the sketch will show the truth of these facts. The practical form of the shunt box is shown in Fig. 47.

Usually the total resistance of the box is either 1000ω, 10,000ω, or 100,000ω, but it will be equally obvious that any value might be chosen. It is, however, advisable not to have too great a disparity between the resistance of the galvanometer and the total of the shunt box, as this leads to loss of sensitiveness.

Fig. 47.—A universal shunt box.

A notable advantage gained by using the universal shunt is that the resistances required are mostly whole numbers, and where not so, the values are quite simple and readily obtained fractions. This is a remarkable advance upon the $\frac{1}{9999}$ of 8576ω which would have to be calculated and provided for an instrument of 8576ω shunted $\frac{1}{1000}$. The fact that the new shunts may be applied to any galvanometer without reference to, or knowledge of, its resistance cannot be too highly estimated.

Galvanometer Constant.

In order to employ a galvanometer for the purpose of measuring currents it is necessary to know its constant. The constant of a galvanometer may be defined as the current required to produce a deflection of one division, and for the P.O. Tangent galvanometer this constant is $\frac{1}{80}$ m.a. The instrument is adjusted by means of the controlling magnet until its constant is 80 divisions per

milli-ampere flowing through it. Both coils in series are used in this case, giving the full resistance of 320Ω.

Formerly the standard Daniell cell described upon page 38 was used in conjunction with the galvanometer for obtaining the constant. The E.M.F. of this cell when carefully made up is 1·08 standard volts. The standard cell was joined up to the galvanometer with a resistance of 750Ω and, assuming the internal resistance as 10Ω, the current was :—

$$\frac{1{\cdot}08}{320 + 750 + 10} = 1 \text{ m.a.}$$

Thus a known current of 1 m.a. was passed through the instrument, which was adjusted in sensitiveness by means of the controlling magnet, until a deflection of 80 divisions was produced. The value of any deflection subsequently obtained could at once be stated.

The resistance of the standard cell was taken as 10Ω, but this assumption proving incorrect, provision was made for ascertaining the actual value by a test made in conjunction with the battery testing instrument. The corresponding value of the deflection which should result when 80 divisions represented 1 m.a. was tabulated for various battery resistances. As an example let the resistance of the standard cell be 7Ω :—

$$\text{current} = \frac{1{\cdot}08}{750 + 320 + 7} = 1{\cdot}003 \text{ m.a. approx.}$$

If 1 m.a. = 80 divisions
then 1·003 m.a. = 80 × 1·003 = 80·24 or 80¼ divisions.

In this case the galvanometer would be adjusted so that the cell produced 80¼ divisions due to the 1·003 m.a. passing through it.

The whole of the resistances and E.M.F.s quoted are in standard ohms. If the galvanometer and 750Ω coil were wound in B.A. ohms, the correcting factor would be much larger. It may, however, be remarked, that the majority of the instruments have been re-wound, and are marked "standard ohms." The 750Ω resistance occupied the position which is now devoted to the ⅛ shunt (Fig. 26).

The standard Daniell cell is open to certain very definite

objections. Firstly, its E.M.F. is dependent upon the strength of the zinc sulphate solution, and therefore considerable care in making it up is necessary. Secondly, being wet and liable to be accidentally overturned, it is not a particularly desirable adjunct to an instrument room. These objections led to the use of a very different arrangement, viz. the "sealed standard cell." This consists of a single dry cell with a resistance coil of 1144$^{\omega}$ placed in a small wooden box, the lid of which is protected by a special seal. The box carries a brass frame in which is inserted a card giving the value of the deflection which must be produced upon a galvanometer in order that 80 divisions may represent 1 m.a., and also the date upon which the cell is to be returned for verification. It is returned to the Engineer-in-Chief's Office every three months, where the box is opened and the E.M.F. of the cell carefully measured. Should the E.M.F. have diminished the value of the deflection necessary is re-calculated and entered upon a new card, which is substituted for the old one.

As the internal resistance of the standard cell is negligible a current of 1 m.a. would be produced if its E.M.F. happened to be precisely 1·464 volts. The relation between its actual E.M.F. and the corresponding deflection which must be obtained in order that 80 divisions shall represent 1 m.a. is obtained precisely as indicated in the case of the old arrangement described on page 123.

One advantage gained by inserting the resistance of 1144$^{\omega}$ in the box itself is that, should the cell be accidentally short-circuited, the resulting current (about $1\frac{1}{4}$ m.a.) will not be such as to cause a serious and permanent change in the E.M.F. of the cell. Without the resistance coil, such an accident would inevitably produce a most serious drop in the value of the cell's E.M.F.

Taking Constant.

In taking the constant the following operations are necessary:—

1. Remove the controlling magnet and place it some distance away.

2. Turn the instrument until the pointer stands opposite the zero of the outer scale. (Note that the needle is not

bent, by observing if the other end lies over 60° on the lower right-hand scale of degrees.)

3. Join up the standard cell by means of the switch and observe the deflection. (The cell should only be kept on long enough to obtain a reading, and the switch should therefore be opened as quickly as possible.)

4. The magnet should be slid to the top of the stalk and—

(*a*) If the deflection obtained without the controlling magnet is *above* the value shown upon the standard cell card the stalk should be placed in its socket and its North pole turned towards the South (*i. e.* its North pole opposite the needle's South). It should then be slightly twisted until the needle is exactly at zero.

or (*b*) If *below*, the North pole of the magnet should face North (*i. e.* its North pole opposite the needle's North). It should then be slightly twisted until the needle is exactly at zero.

5. The stalk should then be clamped by the socket screw.

6. The standard cell should be applied, and the magnet lowered upon the stalk until the requisite deflection is obtained. The cell should be kept on for as short a time as possible, hence it is preferable to make a series of tests rather than to keep the cell running the whole time the magnet is being lowered.

In connection with these operations, the use of the key which short-circuits the 2-circle 4-circle coil when depressed is required in order to quicken the processes detailed in 3 and 6. The joining up of the standard cell would cause the needle to swing well past its proper deflection, and it would oscillate above and below this latter point for some time before coming to rest. By momentarily short-circuiting one coil of the galvanometer the needle is checked in its swing and is urged to return to a lower deflection. By suitable tapping upon this key at the moment of a swing in the direction of increased deflection the needle can very rapidly be brought to rest. With a very little practice the needle can be brought to

rest with considerable expedition. It will be obvious that the same procedure may be applied to any other form of test with this particular instrument.

It occasionally happens that the pointer of the tangent galvanometer is not accurately set with respect to the needle. When one end of the pointer stands at the zero of the outer scale the other end should stand at 60° on the opposite scale of equal degrees. This proves that the pointer is straight, but not that it is at right angles to the magnetic needle. Where such a defect is suspected a deflection of 200 divisions should be obtained by applying about 50 or 60 volts through a sufficient amount of resistance. The resistance of the circuit should then be doubled by adding resistance equal to the galvanometer resistance (320ω), battery resistance and that previously introduced. If the deflection is not exactly 100 divisions, the needle requires adjustment. The pointer should be bent and set at zero, and the whole operation repeated until doubling the total resistance of the circuit exactly halves the deflection.

Constant of Reflecting Galvanometer.

With a reflecting galvanometer the constant is taken in a similar manner, but usually considerable accuracy is required, and therefore a Clark cell is employed. A resistance of 10,000ω or 100,000ω is inserted with the cell and galvanometer. The galvanometer is usually heavily shunted.

As an example suppose that the Clark cell E.M.F. 1·433 volts (at the temperature at which the test is made) is joined to a 5000ω galvanometer shunted $\frac{1}{100}$ through a resistance of 100,000ω, and that a deflection of 200 divisions resulted—

Resistance of galvanometer and shunt	= 50ω
Standard cell about	50
Resistance coil 100,000	100000
Total	100,100

$$\therefore \text{ total current } = \frac{1{\cdot}433}{100100} = {\cdot}01432 \text{ m.a.}$$

Current through galvanometer = ·0001432 m.a.
Value of 1 division = ·0000716 m.a.

Reflecting galvanometers are, however, very frequently used in the same manner as the testing set described in Chapter XX.

CHAPTER IV

BATTERY TESTING.

Measurement of E.M.F.—Direct Deflection Method.

THE current flowing through a circuit is directly proportional to the E.M.F. applied, and inversely to its resistance. If two circuits have equal resistances, the respective currents flowing through them will be directly proportional to the E.M.F.s which they contain. It is upon this fact that the "direct deflection method" of measuring the E.M.F. of a cell depends. The resistance of a circuit, containing in series a battery and a galvanometer, is made up of two parts, the resistance of the galvanometer and the internal resistance of the cell. In substituting another cell for the one included in the circuit described, the internal resistance of the new cell is substituted for that of the first cell. In practice, the internal resistance of ordinary primary cells ranges from $\frac{1}{10}^{\omega}$ to 20^{ω}, and, taking the two extremes as the respective values of the new cell and the first cell, the substitution has involved a decrease of $19{\cdot}9^{\omega}$ in the resistance of the circuit. If the E.M.F.s of the two cells be exactly equal, this decrease in the resistance of the circuit entails an increased current through the galvanometer. This increase of current may be made as small as is desired by increasing the resistance of the galvanometer employed, or by adding resistance to the circuit. In the tests, the external resistance is the same for the first cell as for the second cell, and the increase of resistance means that an amount may be added to the circuit, but that it shall be the same for both tests.

Suppose now that the two cells in question are in turn connected to a P.O. tangent galvanometer of 320^{ω} resistance and that their E.M.F.s are equal, whilst their internal

resistances are respectively ·1ᵒʰ and 20ᵒʰ. The substitution of the ·1ᵒʰ cell for the 20ᵒʰ cell will produce a decrease of nearly 6% in the total resistance of the circuit, and therefore an increase of rather more than 6% in the current. If now 660 be added to the galvanometer by means of a resistance box, the external resistance of the circuit will be raised to 980ᵒʰ (total 1000ᵒʰ), and the substitution of the cells will then produce an increase of but 2% in the value of the current. By taking a more sensitive galvanometer and making the total resistance 10,000ᵒʰ the increase in the value of the current becomes one-fifth of one per cent. With 100,000ᵒʰ it becomes one-fiftieth of one per cent. Therefore it will be seen that this difference in the resistance of the circuit may be reduced to any desired value. In other words, it is only necessary to decide upon what accuracy is required and to calculate the external resistance necessary.

If the two cells differ also in E.M.F., the relative values of the currents which they will produce through the circuit will be in direct proportion to their respective E.M.F.s, subject, however, to the error which their differing internal resistances will produce. It has already been shown that, by making the external resistance correspondingly great, this error may be reduced to any desired value. The current on a tangent galvanometer with its scale divided into degrees is proportional to the tangents of the angles of deflection, therefore the E.M.F.s are directly proportional to the relative tangents of the angles of deflection. For instance, if a cell having an E.M.F. of $\frac{1}{2}$ volt produces a deflection of 30°, and another cell under the same conditions shows 60°, their E.M.F.s are as tangent 30° is to tangent 60°, which is as 1 : 3. The E.M.F. of the second cell is therefore $1\frac{1}{2}$ volts.

Where a tangent galvanometer with a scale divided into equal current divisions, such as the P.O. form, or a reflecting galvanometer, is employed, the E.M.F.s are directly proportional to the number of divisions of deflection produced. If, for instance, a cell having an E.M.F. of 1·3 volts gives a deflection of 50 divisions, whilst a second cell of unknown E.M.F. produces 70 divisions, its E.M.F. is $\frac{70}{50} \times 1{\cdot}3$ volts $= 1{\cdot}82$ volts.

Practically then, this method of measuring E.M.F.s depends upon making the external resistance so large in comparison with the internal resistance that the resistance of the circuit, as a whole, may be considered to be to all intents and purposes the same, no matter what may be the particular value of the internal resistance of the cell under test. If the resistance of the circuit is the same, the current produced depends solely upon the E.M.F. of the cell.

The foregoing method serves only for the purpose of *comparing* the E.M.F.s of two cells, and unless the E.M.F. of one of the cells is known, only the relative E.M.F.s of the cells can be given. If one of the cells had been a standard cell with an E.M.F. of known value, the E.M.F. of the other could readily be stated.

In order to measure the E.M.F. of a cell it is essential that a standard cell should be used. The fact that the galvanometer, or galvanometer and resistance-coils together, should have a high resistance has already been dilated upon. The other point which requires mention is that the galvanometer employed must be of a form in which there is a definite relation between the current and the deflection produced, as for example a tangent galvanometer, a reflecting galvanometer, or other similar instrument. Such an instrument as a differential galvanometer (Fig. 101) would be quite useless, as the deflections do not correspond in any simple way to the currents producing them.

In carrying out a measurement by the direct deflection method a single current key should be joined in circuit so that the cells may only be furnishing current whilst the deflection is being read. This precaution is necessary to avoid errors due to polarization, and it may be remarked that the higher the resistance of the circuit the smaller is the polarization.

A deflection is first taken with the standard cell in circuit, and the cell whose E.M.F. is to be measured is then substituted for it. The relative E.M.F.s are in the same proportions as the number of divisions of the deflection produced.

Example.—A standard cell 1·08 volts gives a deflection of 120 divisions upon a high resistance galvanometer. What is the E.M.F. of another cell which produces 197 divisions under like circumstances?

$$120 : 197 :: 1{\cdot}08 : \text{E.M.F.}$$

$$\therefore \text{E.M.F.} = \frac{197 \times 1{\cdot}08}{120} = 1{\cdot}773 \text{ volts.}$$

With an ordinary tangent galvanometer the deflections should be as near to 45° as possible, in order to ensure the maximum accuracy in reading the deflections. With a P.O. instrument 110 divisions represent the greatest accuracy, and with a reflecting galvanometer the larger deflection should be as near to the maximum of the scale as practicable.

Equal Current Method.

The direct deflection method gives the E.M.F. of the standard cell and the cell or battery under test as proportional to the respective deflections produced. If now the battery under test consists of, say, fifty cells, and if, for the sake of illustration, its E.M.F. is assumed to be fifty times that of the standard cell, the respective deflections produced will be as 1 : 50. If the first deflection is 4 divisions, the second will be 200. This latter can be read with sufficient accuracy—say to within a half division—a like accuracy in the first deflection means that it may be read as 4 when actually it may be $3\frac{1}{2}$ or even $4\frac{1}{2}$. If the E.M.F. of the standard cell is 1 volt, the E.M.F. of the battery would be given as $57\frac{1}{7}$ volts for $3\frac{1}{2}$ divisions, 50 volts for 4 divisions or $44\frac{4}{9}$ volts for $4\frac{1}{2}$ divisions. The errors in practice would amount to far more than these values—probably to twice as much.

It will be apparent, then, that the direct deflection method should only be used to compare the E.M.F. of two cells, or to compare the E.M.F. of two batteries of approximately equal E.M.F. Where this method breaks down, the "equal current method" may, with advantage, be employed.

The equal current method depends upon the fact that if two circuits carry an equal current, the E.M.F.s producing those currents are in direct proportion to the respective total resistances of the two circuits. For instance if the resistances of the two circuits were 2000$^{\omega}$ and 1000$^{\omega}$ it would require twice the E.M.F. to furnish the same current in the first circuit as would be required in the second.

In the above statement the total resistance of the circuit

is distinctly specified, thus necessarily including the internal resistance of the batteries. The same arguments must be applied to this case as those applied in the direct deflection method. The conclusion is that here also the external resistance must be made large in comparison with that of the internal resistance of the cell. This point will, however, be rendered more apparent after a consideration of the practice of the method.

A galvanometer, key, and rheostat are joined up to the standard cell as shown in Fig. 48. The galvanometer may

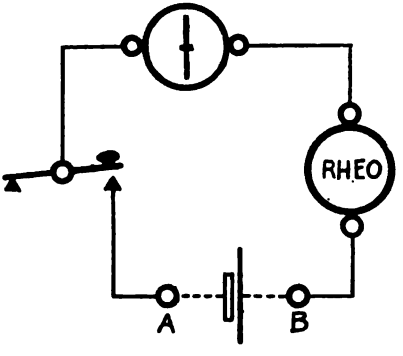

FIG. 48.—Equal current method of measuring the E.M.F. of a battery.

be of any form, since the method merely requires that the current shall be the same under two different conditions. The relation of the deflection to the current producing it is quite immaterial, since the same deflection means the same value of current, whatever it may be. The sensitiveness of the instrument should be such that, when the external resistance with the standard cell in circuit is of the value chosen, a large and clearly readable deflection as near the angle of maximum sensitiveness as possible, shall be obtained. For an ordinary tangent galvanometer this should be 45° and with a P.O. differential galvanometer (Fig. 101) about 35°.

Let the resistance of the galvanometer (Fig. 48) be 50 and the resistance introduced in the rheostat be 450. With the standard cell E.M.F. 1·08 volts connected between *A* and *B*, a deflection of 50° upon the galvanometer is pro-

duced upon depression of the key. The battery to be tested is then substituted for the standard cell between *A* and *B*. The resistance in the rheostat is raised (to say 5760Ω) until the depression of the key produces exactly the same deflection, viz. 50°. The currents in the two cases are therefore the same, and, since the external resistances are greatly in excess of the internal, the rule previously deduced may with propriety be applied, viz. that the E.M.F.s are proportional to the respective external resistances. The E.M.F. of the standard cell (1·08 volts) is then in the same proportion to that of the battery tested as their external resistances, that is as 50Ω + 450Ω : 50Ω + 5760Ω or as 500Ω : 5810Ω.

$$500 : 5810 :: 1{\cdot}08 : \text{E.M.F.}$$

$$\therefore \text{E.M.F.} = \frac{5810 \times 1{\cdot}08}{500} = 12{\cdot}55 \text{ volts.}$$

Here it will be well to investigate the error introduced by the difference in the internal resistance of the cells tested. Let the standard cell have a resistance of 20Ω, and the battery under test ·1Ω per cell. For simplicity of calculation assume that the E.M.F. of the standard cell is 1 volt, and that of the ten-cell battery is 10 volts. Equal deflections would be obtained with an *external* resistance of 480Ω for the standard cell, and 4999Ω for the battery, the total resistances being respectively 500Ω and 5000Ω. This is, of course, exactly the ratio of the two E.M.F.s; but, in neglecting the internal resistances as laid down in the method described, the ratio is given as 480 : 4999. This corresponds to an error of approximately 4%. Had the total resistance been 1000Ω for the first test, the error would have been 2%, whilst if 2000Ω had been employed in the first instance with the standard cell, the error would only have amounted to 1%. In practice, the internal resistances would not be likely to differ so widely and the errors would therefore be smaller—probably less than half as great. With ordinary telegraph cells the first value (500Ω) would be quite accurate enough. The accuracy with which the deflection could be read would probably not be much nearer than 1%, and the second value (1000Ω) would meet every requirement.

The error introduced by the difference in the resistance of the standard cell and the battery tested, is not proportional to the ratio of the resistance of the standard cell to the total resistance of the battery tested. If the standard cell and the E.M.F. per cell of the battery tested are equal, and their internal resistances per cell are also equal (say 10^{ω}) the resistance of the standard cell is 10^{ω}, whilst that of the battery (say 50 cells) is 500^{ω}. In this case no error whatever is introduced since the resistances per cell are equal. Where the E.M.F. per cell differs, the internal resistances per cell should bear the ratio of the E.M.F.s to obviate error.

Wiedemann's Method.

Wiedemann's method of comparing the E.M.F.s of two batteries depends solely upon the accuracy with which the deflections can be read. The internal resistance of the cells does not enter into the question at all, but, like the direct deflection method, it suffers from the disadvantage that it is only accurate when the E.M.F.s of the cells or batteries compared do not widely differ.

A tangent galvanometer, rheostat, and key, are joined up with the standard cell and the cell to be tested, in series. The standard cell and the cell under test act in the same direction, and therefore the current through the apparatus is proportional to the sum of their E.M.F.s. The resistance in the rheostat is then adjusted until a fairly large deflection is obtained. One of the cells is now reversed so that, upon depression of the key, they tend to send currents in opposite directions. Since the resistance of the circuit is unchanged, the current produced is therefore proportional to the difference of their E.M.F.s.

If the two cells are equal in E.M.F. there will obviously be no deflection in the second case. The general rule is :—*The E.M.F. of the greater is to the E.M.F. of the lesser as the sum of the deflections is to their difference.*

It is essential that it should be known which cell has the larger E.M.F., and it is also necessary that when one cell is reversed the cell reversed shall have the lesser E.M.F. If this latter point were not observed the use of a skew scale galvanometer would not be possible, as the "difference" deflection would be in the reverse direction to the "sum"

deflection. With an ordinary tangent galvanometer there would still be a complication, but as it is so easy to avoid, this point is not worth following up.

Example.—Two cells acting together give a deflection of 198 divisions and acting in opposition, due to reversal of the standard cell, 35 divisions, what will be the E.M.F. of the first cell if the E.M.F. of the standard cell is 1·08 volts?

If the standard cell was the cell which was reversed, *i. e.* and had the lesser E.M.F., then

$198 - 35 : 198 + 35 :: 1{\cdot}08$ volts : E.M.F. of cell tested,

or $163 : 233 :: 1{\cdot}08$: E.M.F. of cell tested

$$\therefore \text{E.M.F.} = \frac{233 \times 1{\cdot}08}{163} = 1{\cdot}544 \text{ volts.}$$

It may be remarked that although the method does not depend upon the value of the resistance of the circuit this should be made high in order that the current taken from or passing through the standard cell may be a minimum. This avoids two evils, damage to the standard cell and polarization.

Potentiometer Method.

The most accurate method of measuring E.M.F.s is the potentiometer method. It further possesses the advantage of being a "null" or "zero" method, which term is another way of saying that it does not depend upon the observation of the value of a deflection. The galvanometer is merely used to *indicate* a difference of potential, and not to *measure* it.

A long wire of uniform section and high resistivity is stretched above a scale of equal divisions between two terminals. A contact point with a terminal attached slides over the wire. A secondary cell with an adjustable resistance is connected to the two ends of the wire and a steady current of suitable value flows along it. This current must not be so great as to cause any serious heating of the wire. The difference of potential between the ends of the wire is equal to the current flowing through it multiplied by its resistance. Similarly, the difference of potential between any two points is equal to the current multiplied by the resistance of the wire between the two points.

The point marked 0 (Fig. 49) will be called zero, and

the potentials along the wire considered with respect to it. For the moment the cell and galvanometer shown below the wire should be ignored. The current in the wire is, of course, of the same value throughout its length. The potential difference between 0 and 100 is equal to the current multiplied by the resistance of the wire between 0 and 100. The potential difference between 0 and 50 is obviously half this value, since the resistance of the wire is assumed to be quite uniform and therefore directly proportional to its length. Similarly the difference of poten-

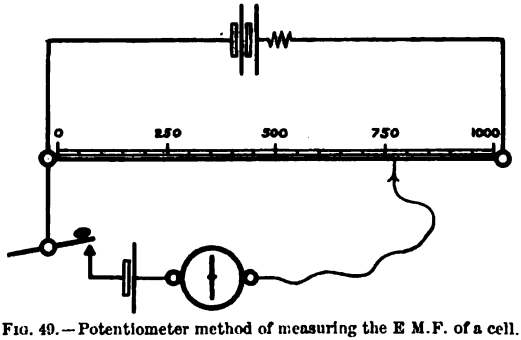

FIG. 49.—Potentiometer method of measuring the E M.F. of a cell.

tial between 0 and any point along the wire is directly proportional to the length of the wire from 0 to that point. For example the difference of potential between 0 and 75 is $\frac{3}{4}$ of that between 0 and 100, or is $1\frac{1}{2}$ times that between 0 and 50.

If now one end of a standard cell, with a galvanometer in series with it, be attached to the 0 end of the wire, whilst the other terminal is connected to the slider, a point can be found upon the slide wire where the difference of potential from 0 to that point is equal to the E.M.F. of the cell. Such a point is found by moving the slider until the galvanometer shows no deflection. When this is the case the difference of potential between 0 and the slider is equal to the E.M.F. of the cell. Since no current flows under these conditions the difference of potential between the negative pole of the cell and the opposite end of the galvanometer is clearly the same as that between the terminals of the cell. If this were not so, there would be a

difference of potential between the terminals of the galvanometer, but this is not the case since there is no deflection.

The difference of potential between 0 and the slider has now been determined, since it is known to be equal to the E.M.F. of the standard cell. Assume that the E.M.F. of the standard cell is 1·434 volts, and that the point at which the slider stands, for brevity usually termed the "reading," is 760 divisions. Therefore 760 divisions equal 1·434 volts and one division will therefore be equal to $\frac{1}{760}$ of 1·434 volts. The standard cell is then removed and its place taken by the cell to be tested. The same procedure is followed and a place is accordingly found where there is no deflection. Let this reading be 580 divisions. The difference of potential per division has already been found to be $\frac{1{\cdot}434}{760}$ volts, therefore 580 divisions represent 580 times as much. The E.M.F. of the cell is therefore—

$$580 \times \frac{1{\cdot}434}{760} = 1{\cdot}094 \text{ volts.}$$

The operation of finding the null point is very greatly simplified by the fact that the direction and magnitude of the deflection are determined by the distance of the slider from the point of balance. In the case cited the galvanometer would be deflected by the main battery overpowering the standard cell if the slider occupied a position to the right of the balance. This deflection would be largest at 1000, and would gradually reduce in value until it vanished at the null point, which in this case is 760. Upon the other side of the null point the standard cell would have a path along the slide wire, thus giving a reverse deflection, and the deflection would gradually increase until it reached a maximum at 0.

The accuracy of the method is only limited by the accuracy with which the slide wire divisions can be read. This may greatly be increased by the use of a vernier. There are, however, two distinct assumptions made in the course of the tests, firstly that the current flowing along the slide wire is absolutely invariable, and secondly that the slide wire is absolutely uniform in resistance. The first assumption holds good if a secondary cell or cells are employed and the measurements are taken in rapid

succession. The second one is not so readily met, the wire never is uniform, and, even if it were, it would very soon be damaged by continual use. This difficulty may be met by calibration, *i. e.* determining the resistance of the wire between a large number of points.

Consideration will show that the cell to be tested may be applied to the wire with a second slider, whilst the standard cell is also connected. In this way, by watching both galvanometers it can be made quite certain that the value of the current through the slide wire is absolutely the same for both tests.

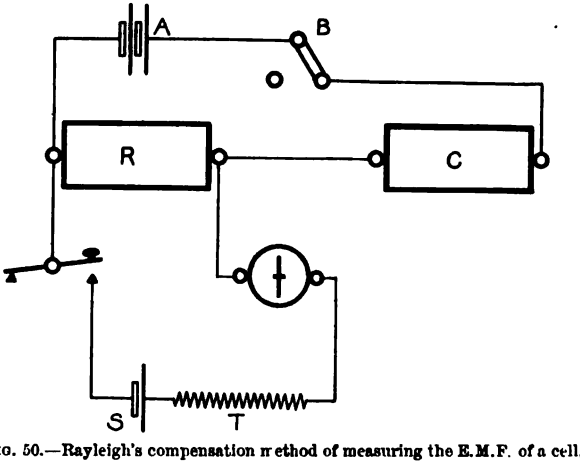

FIG. 50.—Rayleigh's compensation method of measuring the E.M.F. of a cell.

The potentiometer methods of measurement loom very large in the future, for the possibilities of the application of the principles there enunciated render the accurate measurements of E.M.F. and current quite simple.

RAYLEIGH'S COMPENSATION METHOD.

Rayleigh's compensation method of accurately comparing the E.M.F.s of two cells depends upon precisely the same principle, but may be carried out far more accurately than is possible with a slide wire, and, moreover, merely requires apparatus to be found in any test room.

Two boxes of coils, R and C (Fig. 50), each of which will give any integral value of resistance up to at least 10,000ω, are connected together by a short piece of thick wire and a current from one or even two secondary cells is caused to flow through both in series. The resistance between the terminals of the battery is kept constant at 10,000ω, *i.e.* the resistance unplugged in R added to that of C is always kept equal to 10,000ω. When R is increased C is reduced by an exactly equal amount. The standard cell, together with a highly sensitive galvanometer, a large resistance coil T, and a suitable key, are connected to the ends of R. R is then adjusted until no deflection is shown upon the galvanometer when the key is depressed. With each increase of resistance in R, C is decreased by exactly the same amount, thus keeping the sum of R and C constant at 10,000ω. The difference of potential between the ends of R is equal to the E.M.F. of the standard cell. The value of R is noted and the cell to be tested is then substituted and R is readjusted until no deflection is obtained when the key is depressed. As in the previous test R and C together must be kept at 10,000ω during the whole process.

The object of the coil T, which may have a resistance of from 100,000ω to 200,000ω, is to prevent any large value of current from flowing through the galvanometer and cell owing to any accidental mistake.

A numerical example of the method is appended :—

The standard cell E.M.F. 1·434 volts balanced when R was 7352ω and the cell under test when R was 6853ω. What is the E.M.F. of the cell tested ?

$$7352\omega : 6853\omega : : 1{\cdot}434 : \text{E.M.F.}$$

$$\therefore \text{E.M.F.} = \frac{6853 \times 1{\cdot}434}{7352} = 1{\cdot}3367 \text{ volts.}$$

It may be remarked that when R was 7352ω C must have been $10000 - 7352 = 2648\omega$ and when 6853ω C must have been 3147ω. The direction and magnitude of the deflection obtained when altering R serves as a guide in finding the required value. The actual operations would probably be as follows in the case of the first reading.

R.	*C*.	*R* and *C*.	Direction of deflection.	Conclusion.
5000	5000	10,000∞	Left	This is the direction of the standard cell's current .·. *R* is too small.
8000	2000	,,	Right	*R* too large. Value lies between 5000 and 8000.
7000	3000	,,	Left	*R* too small. Value lies between 7000 and 8000.
7500	2500	,,	Right	*R* too large. Value lies between 7000 and 7500.
7300	2700	,,	Left	*R* too small. Value lies between 7300 and 7500.
7400	2600	,,	Right	*R* too large. Value lies between 7300 and 7400.
7350	2650	,,	Left	*R* too small. Value lies between 7350 and 7400. The deflection is so slight as to show that the balance is very near.
7355	2645	,,	Right	*R* too large. Value lies between 7350 and 7355.
7352	2648	,,	Nil	Balance at 7352.

Modern Forms of Potentiometer.

It may be interesting to note the general lines upon which modern potentiometers have been developed from the simple form previously described and also to indicate in a general way the almost universal utility of the arrangement. For measurements in which the E.M.F. of the standard cell and that to be measured differ very widely an enormous length of carefully calibrated slide wire would be required. Moreover the possibility of any slight damage rendering recalibration necessary is most serious. In the Crompton type a single length slide wire is employed, but this is supplemented by fourteen coils placed in series with it, each coil being equal to one length of

the slide wire. The constant resistance between its terminals is therefore equal to fifteen lengths of slide wire and the arrangement corresponds to a slide wire fifteen times the length of the one provided and divided into some 15,000 equal divisions. A radial contact arm moves over the junctions of the various coils, and this with the slider, which moves along the slide wire, form the two points between which the standard cell and galvanometer are joined. If the radial arm stood at 11 whilst the slider stood at 736 the reading would be 11,736. A couple of rheostats are included in the circuit of the slide wire and coils in order to adjust the value of the current through them from the single storage cell employed. In this way the instrument may be made to read direct, and thus save a large amount of time which would otherwise be spent in arithmetical calculations. Suppose the E.M.F. of the standard cell is 1·434 volts. The radial arm is set at 14, whilst the slider is placed at 34, and by means of the rheostats mentioned, the current is adjusted until no deflection is produced. When this is the case each coil represents $\frac{1}{10}$ volt and each division $\frac{1}{1000}$ volt. The E.M.F. of any cell is then given as one thousandth of the reading obtained.

Any current may be measured by measuring the difference of potential it produces across the ends of a known resistance, and standard resistances to take such huge currents as 2000 amperes have been designed for use in this way. Similarly, high voltages may be measured by joining up to the *circuit* a series of 10,000$^{\omega}$ coils and measuring by the potentiometer the difference of potential across a sub-division of one of them. For example, to measure 1500 volts ten coils of 10,000$^{\omega}$ each would be joined across the source of E.M.F. One of these coils has a tap at 100$^{\omega}$, and across its ends the potential difference will be $\frac{1}{1000}$ of the total E.M.F., *i. e.* about 1·5 volts. This difference is of the same order as the E.M.F. of the Clark cell, and it will therefore be recognized that its measurement can be carried out with the utmost accuracy.

Messrs. Nalders, upon the other hand, have gone still further than Crompton, and have abandoned the slide wire altogether. In place of the slide wire is a series of one hundred exactly equal resistance coils, with a radial arm moving over their junctions. A second set of 150 coils

each equal to 100 times the resistance of each of the first set is connected in series with the first set and a similar radial contact arm moving over the junctions of the 150 coils is provided. As in the Crompton form, an adjustable rheostat is provided to obtain direct readings in volts. The arrangement corresponds to a slide wire with 15,000 fixed contacts and to measure high voltages a potential divider similar in principle to that already described is employed. The absence of a slide wire is distinctly desirable since it is obviously liable to injury, but at the same time it may be remarked that its presence means superior fineness of adjustment.

The potentiometer is of almost limitless value in accurate electrical measurements, whilst the principles underlying its use are as simple as they are valuable. The methods described may, however, be carried out by means of a few sets of resistance coils or Wheatstone Bridges (as in the Rayleigh method of measuring E.M.F.). The beautiful instruments above described are luxuries, and though they are now found in good laboratories they may be substituted as mentioned.

Summary of Methods of Measuring E.M.F.

The tabular statement below gives a summary of the methods discussed.

Method.	E.M.F.s of cells compared are proportional to—	Type of galvanometer to be employed.
Direct deflection	The deflections produced upon a high resistance galvanometer.	Tangent or reflecting.
Equal current	The external resistances of the circuit under the two conditions.	Any type, provided it is sufficiently sensitive.
Wiedemanns	Respectively to the sum and to the difference of the two deflections.	Tangent or reflecting.
Potentiometer	Readings obtained.	Any highly sensitive type.
Rayleigh	Resistances in the first box.	Ditto.

Measurement of Internal Resistance.—Half-Deflection Method.

The "half deflection" method of measuring the internal resistance of a cell or battery is one of the simplest and easiest tests to carry out. The only apparatus required is a tangent or a reflecting galvanometer and a set of resistance coils.

The principle of the method may be stated as follows:—If the *current* through a circuit, due to a constant E.M.F., is *halved*, then the *resistance* of that circuit must have been *doubled*. For instance, 20 volts applied to a circuit having a total resistance of 1000$^{\omega}$ produces a current of 20 m.a. Now the resistance of the circuit must clearly be doubled in order to reduce the current to half its former value, viz. to 10 m.a. Firstly it will be well to consider the simplest case in which the resistance of the galvanometer is far less than the internal resistance of the battery and in which the battery connected to the galvanometer gives a convenient deflection without the aid of added resistance.

The cell or battery to be tested is joined up in series with the galvanometer, a key, and a set of resistance coils. No resistance is inserted in the resistance box, and, upon completion of the circuit, a large and easily read deflection is obtained. This deflection is then reduced to half its former value by introducing resistance into the circuit by means of the set of coils. When this has been done the resistance unplugged is equal to the internal resistance of the battery or cell. This is obviously so since the total resistance of the circuit was at first equal to the internal resistance of the battery or cell tested (galvanometer resistance and resistance box assumed to be negligible). In the second case the resistance unplugged doubled the resistance of the circuit, therefore this amount must be equal to the resistance of the circuit before it was inserted.

The conditions here laid down are readily fulfilled by a reflecting galvanometer shunted by a few inches of No. 20 copper wire. This sufficiently reduces the sensitiveness of the galvanometer and at the same time renders its resistance quite negligible.

The next case to be considered is where the resistance of the galvanometer cannot be neglected and where resistance has to be added to the circuit to obtain a satisfactory deflection. These values are noted, and the resistance raised until the deflection in tangent divisions is halved. In this case the resistance of the circuit has obviously been doubled since the current through the circuit is reduced to one half. Now the *added* resistance is therefore equal to the resistance of the circuit before its addition, *i. e.* it is equal to the internal resistance of the battery, the resistance of the galvanometer and the resistance inserted in the rheostat for the first test, added together.

Example.—The P. O. tangent galvanometer shunted $\frac{1}{10}$th is joined up with 40$^{\omega}$ in the rheostat and a deflection of 180 divisions is produced. This is reduced to 90 divisions by raising the resistance in the box to 150$^{\omega}$.

What is the internal resistance of the battery?

Resistance added in box = 150 − 40 = 110$^{\omega}$.

Added resistance = Battery + Galvo. + Res. in box for 1st test.

i. e. 110 = Battery + 8 + 40

110 = Battery + 48

∴ Internal resistance = 110 − 48 = 62$^{\omega}$.

The rule for finding the internal resistance from the above data has been designedly omitted, since it is usually memorized to the obscurement of the very simple and useful principles involved in the test.

The best conditions for the accuracy of the result of the half-deflection method are when the resistance of the external circuit in the first test is as small as possible as compared with the internal resistance of the battery to be tested. This will readily be seen to be so by consideration of a case in which a large departure from the best conditions is made. The whole question turns upon the accuracy with which the galvanometer deflection can be read. This will usually be to about one half of one per cent. For instance, a deflection which was actually $99\frac{3}{4}$ or $100\frac{1}{4}$ would be read as 100, because the divisions are so small that, in the two cases cited, the divergence from 100 divisions is too slight to be seen and appraised. It will

now be necessary to investigate the effect of this possible error in reading the deflection upon the result obtained from testing a battery under conditions which differ widely from those laid down.

For simplicity it will be assumed that the first deflection produced is accurately 200 divisions and that the second one is (1) actually $100\frac{1}{4}$ and (2) actually $99\frac{3}{4}$ whilst both are read as 100. Taking the external resistance for the first test as 9936$^{\omega}$ and the battery as 64$^{\omega}$ as before, the value of the resistance added to produce 100 divisions is clearly 10,000$^{\omega}$. The values of the total resistance corresponding to $100\frac{1}{4}$ and $99\frac{3}{4}$ are respectively 19,950$^{\omega}$ and 20,050$^{\omega}$. Deducting the internal resistance of the battery the values of the external resistances are 19,886$^{\omega}$ and 19,986$^{\omega}$, thus giving the resistance of the battery :—

(1) Resistance for second test	19,886$^{\omega}$
Resistance first test	9,936
added resistance	9,950

Internal resistance = 9,950 − 9,936 = 14$^{\omega}$.

(2) Similarly :—
Internal resistance = 114$^{\omega}$.

It will therefore be seen that in the case shown an error of one-half of one per cent. in reading the deflection produces results which differ by 100$^{\omega}$. Another way of stating the result which has been deduced theoretically is to say that the value of the resistance inserted in the rheostat may be varied within the extreme limits of 100$^{\omega}$ without visibly affecting the value of the deflection. In making a test it should always be ascertained within what limits the resistance may be varied, since this at once gives the accuracy to be expected in the result.

Applying the same method to the example of the test given upon page 144, it will be found that the resistance of the battery lies between 61$^{\omega}$ and 63$^{\omega}$, a possible error of about 3%. Although this result would probably be of sufficient accuracy for ordinary tests, its magnitude would have been considerably reduced by a closer observance of

the best conditions, viz. that the resistance of the external circuit for the first test should be nil.

Diminished Deflection Direct Method.

This method is very similar to the half-deflection method, and may be said to be little more than an obvious extension of it. In practice it is often inconvenient to exactly halve a deflection; for instance, in measuring the resistance of a single cell one may not happen to have resistance coils arranged in sufficiently small fractions of an ohm to reduce the deflection to exactly one-half. The problem therefore assumes a slightly more complex form. The connections are precisely as in the half-deflection method. The resistance in the rheostat is adjusted until a convenient deflection is obtained, and this resistance is then raised until the deflection is materially reduced, preferably to about one *third* of its former value. Unfortunately, the resistance of the battery cannot be reasoned out from first principles without the aid of algebra. The formula derived is:—

$$\text{Internal resistance} = \frac{d_2R_2 - d_1R_1}{d_1 - d_2} - G$$

where d_1 is the deflection obtained with R_1 ohms in the rheostat through a galvanometer of G ohms resistance and d_2 is the deflection given when the resistance in the box has been raised to R_2 ohms.

Example.—85 divisions is obtained with 20$^{\omega}$ in the resistance box through a galvanometer of 15$^{\omega}$ resistance, and 30 divisions is obtained when the resistance in the box is raised to 300$^{\omega}$. What is the internal resistance of the battery?

$$\text{Internal resistance} = \frac{30 \times 300 - 85 \times 20}{85 - 30} - 15$$
$$= 117{\cdot}7^{\omega} \text{ approx.}$$

The best conditions for this test are when the smaller deflection is exactly one-third of the larger, and when the galvanometer resistance and the resistance first unplugged in the box are as low as possible.

Thomson Method.

The Thomson method consists in obtaining equal deflections upon a galvanometer, firstly with a resistance connected across its terminals, and secondly with resistance inserted in series with the battery and galvanometer. The test may be carried out with a couple of rheostats and two keys, or with a Wheatstone bridge. The connections in the former case are shown in Fig. 51.

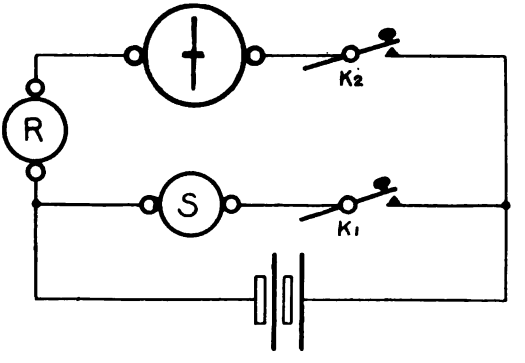

Fig. 51.—Thomson's method of measuring the internal resistance of a battery.

The keys K_1 and K_2 are closed and the resistance in S is adjusted until a deflection, as near the angle of maximum sensitiveness as possible, is obtained whilst R stands at 0. The deflection is then reproduced by adding resistance in R until exactly the same deflection as before is obtained. For this purpose only K_2 is closed. When this has been done the resistance of the battery is equal to the product of the resistances employed at R and S divided by the resistance of the galvanometer.

In practice there is a great deal of risk in employing this method, since the accuracy of the test depends to a remarkable degree upon the observance of the best conditions. The shunt resistance should be less than the internal resistance of the battery, and R should be as large as possible. Assuming that the galvanometer deflection can be read to one per cent., the degree of accuracy obtain-

able is approximately one per cent., with the following values :—

Galvanometer resistance, 250ω, shunt 10ω, and R_1 5000ω.

$$\text{Internal resistance} = \frac{5000 \times 10}{250} = 200\omega.$$

Had S been 100ω the error might have amounted to 2%.

The usual arrangement of this test is slightly more complex than the one given above. Resistance is inserted in R when the deflection is obtained with S across the poles of the battery. The key K_1 is opened and R is again adjusted until the same deflection is produced. When this is the case the resistance of the battery (r) is equal to the second value of R (R_2) minus its first value (R_1) divided by the sum of the galvanometer resistance and the resistance in the rheostat for the first test R_1 :—

$$r = S \frac{R_2 - R_1}{R_1 + G}$$

As previously remarked S should be less than the battery resistance and R_2 should be as large as possible, R_1 added to the galvanometer resistance should be a slightly smaller proportion to the sum of $G + R_2$ than that of S to G. The following example indicates the necessary relative values :—

$$R_1 = 350\omega,\ R_2 = 6{,}200\omega,\ S = 20\omega,\ G = 200\omega$$

$$r = 20 \times \frac{6200 - 350}{350 + 200}$$

$$= 212{\cdot}7\omega.$$

When $R_1 = 0$ the formula becomes—

$$r = S \frac{R_2}{G}$$

By making S equal to the galvanometer resistance r becomes equal to R_2 simply. It is, however, most undesirable to do this, as serious errors result from the departure from the best conditions which the simplification of the formula entails.

The Thomson method, above all others, needs great

rapidity of measurement to avoid polarization troubles. The shunt resistance is always low as compared with the resistance of the battery, and heavy currents therefore result.

Wheatstone Bridge Method.

Another method of measuring the internal resistance of a battery is to divide it into two halves and join these two halves up so that their E.M.F.s oppose. The battery is then joined up to a Wheatstone bridge in the ordinary way and measured like a simple resistance, but both directions of current must be employed. The resistance of the battery is then equal to the square root of the product of the resist-

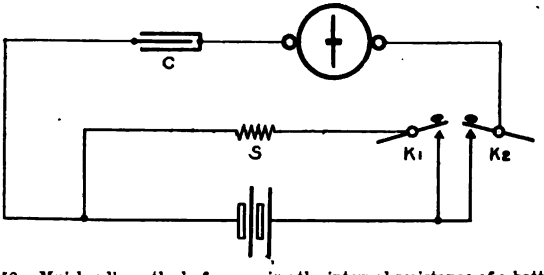

Fig. 52.—Muirhead's method of measuring the internal resistance of a battery.

ances required to balance in the two cases. The method is one of considerable accuracy.

Muirhead's Method.

The internal resistance of a cell or battery can be deduced from the principles which were discussed in Chapter II. It was there shown that, knowing the E.M.F. of a cell and the difference of potential across its terminals when joined by a resistance of known value, its internal resistance could readily be determined.

A method of doing this, invented by Kempe and slightly modified by Dr. Muirhead, is one of the best which has yet been devised, since by very slight alterations the E.M.F. and internal resistance of a battery may be measured whilst the latter is actually working.

A condenser and preferably a ballistic galvanometer are

joined up with a shunt resistance, two keys, and the battery to be tested, as indicated in Fig. 52. Firstly, K_2 is depressed, thus producing a throw (d_1) upon the galvanometer. This is noted and, still holding K_2 down, K_1 is also depressed, resulting in a throw (d_2) in the opposite direction. The internal resistance of the battery is then

$$r = S \frac{d_2}{d_1 - d_2}$$

In practice d_1 should be approximately three times d_2, in order to obtain the maximum amount of accuracy.

The theory of the test is fortunately very simple. When K_2 is depressed the condenser is given a charge proportional to the E.M.F. of the battery. This charge passes through the galvanometer and produces a deflection proportional to its magnitude. The depression of K_1 reduces the potential between the ends of the cell and hence between the ends of the condenser. The condenser partially discharges, the value of the discharge being directly proportional to the reduction in the potential difference across its terminals, which latter is equal to that lost in the cell itself.

A numerical example will perhaps best serve to make this clear :—

A deflection of 300 divisions was obtained upon depressing K_2 and 100 in the reverse direction when K_1 also was depressed. If S was 20^{ω} what is the resistance of the battery?

$$r = 20 \times \frac{100}{300 - 100} = 10^{\omega}.$$

Inspection shows that this result is correct, but its accuracy may be checked by means of the principles proved on page 63.

Resistance of Secondary Cells.

The resistance of a secondary cell or battery cannot conveniently be measured by any of the methods just described, owing to the extremely small resistance and very large currents to be dealt with. A fairly accurate test may, however, be made with the aid of a voltmeter and an ammeter. The battery is connected through the am-

meter to a discharge tank, the resistance of which is adjusted until a current equal to maximum rate of discharge is obtained. The P.D. across the terminals of the battery is then taken, and, leaving the voltmeter connected, the external circuit is broken and the voltmeter again read.

Example.—A voltmeter connected across the terminals of a secondary battery indicates 22·6 volts when the current passing was 150 amperes and 23·1 upon open circuit. What is the internal resistance of the battery?

$$\text{E.M.F. lost in battery} = 23{\cdot}1 - 22{\cdot}6 = {\cdot}5^{\text{v}}$$

$$R = \frac{E}{C} \therefore \text{Internal res.} = \frac{{\cdot}5}{150} = {\cdot}0033^{\Omega}.$$

EDEN BATTERY TESTING INSTRUMENTS.

The method chosen for testing batteries in a large telegraph office must necessarily combine simplicity of manipulation with quickness and accuracy. It must moreover be capable of dealing with different types and different numbers of cells. Two types of instrument, both of which are used in conjunction with the tangent galvanometer, are employed by the Post Office. The highly developed instrument is used at very large offices, whilst the simpler form is employed where the extra rapidity gained by the use of the more costly device is not essential. Throughout the description which follows it is assumed that the constant of the galvanometer has been adjusted.

E.M.F. Test.

It has previously been pointed out that the E.M.F.s of the cells used by the Post Office are:—

Daniell	1·08 volts
Leclanché	1·62 ,,
Bichromate	2·16 ,,

The principle of the test consists in introducing resistance, and in shunting the galvanometer when Leclanché and Bichromate cells are tested, so that a deflection of 100 divisions is produced upon one coil of the galvanometer if the cells have the maximum values of E.M.F. given above.

If the E.M.F.s of the cells tested are below the maximum a correspondingly reduced deflection results. For instance, a deflection of 94 divisions instead of 100 would mean that the cells were 6% below the maximum value. The E.M.F.s of the cells are entered upon the records of the tests as the percentage falls from their maximum values.

The value of the current required to produce a deflection of 100 divisions upon *one* coil of a tangent galvanometer with a constant of 80 divisions for two coils is obtained thus :—

40 divisions on one coil = 1 m.a.
$\therefore$ 100 „ „ „ „ = $2\frac{1}{2}$ m.a.

The total resistance of the circuit, which will have a current of $2\frac{1}{2}$ m.a. due to an E.M.F. of 1·08 volts, is

$$\frac{1{\cdot}08}{{\cdot}0025} = 432^{\omega}$$

The same result may be obtained by noting that 1·080 volts through 1080$^{\omega}$ would produce a deflection of 40 divisions upon one coil. In order to increase the deflection $\frac{5}{2}$ times the resistance must clearly be reduced to $\frac{2}{5}$ of $1080 = 432^{\omega}$.

The internal resistance of the cells tested is taken as 3$^{\omega}$ per cell irrespective of type. The error involved in the assumption is extremely small in view of the very limited range of the resistances of cells used by the Post Office. If, therefore, 429$^{\omega}$ (432$^{\omega} - 3^{\omega}$) is inserted with each cell of a battery having an E.M.F. of 1·08 volts per cell a deflection of 100 divisions will result, irrespective of the number of cells composing the battery under test. For instance, 20 cells would have $20 \times 429 = 8580^{\omega}$ inserted, and with the 60$^{\omega}$ internal resistance the current would be $2\frac{1}{2}$ m.a., which produces 100 divisions.

It will be obvious that if a 10-cell battery produces a deflection of 92 divisions its E.M.F. is $10 \times \frac{1{\cdot}08 \times 92}{100}$ volts or the average E.M.F. of the cells composing it is $\frac{1{\cdot}08 \times 92}{100}$ *i. e.* 8% below the maximum value 1·08.

Turning now to Bichromate batteries it will be noticed

that the maximum value of the E.M.F. per cell is exactly twice that of a Daniell cell. If, therefore, the galvanometer is shunted one half, and 429ω is introduced for every cell under test, a deflection of 100 divisions will result provided that the battery has an E.M.F. of 2·16 volts per cell.

The E.M.F. of a Leclanché is one and a half times that of a Daniell cell, and if the deflection which would result

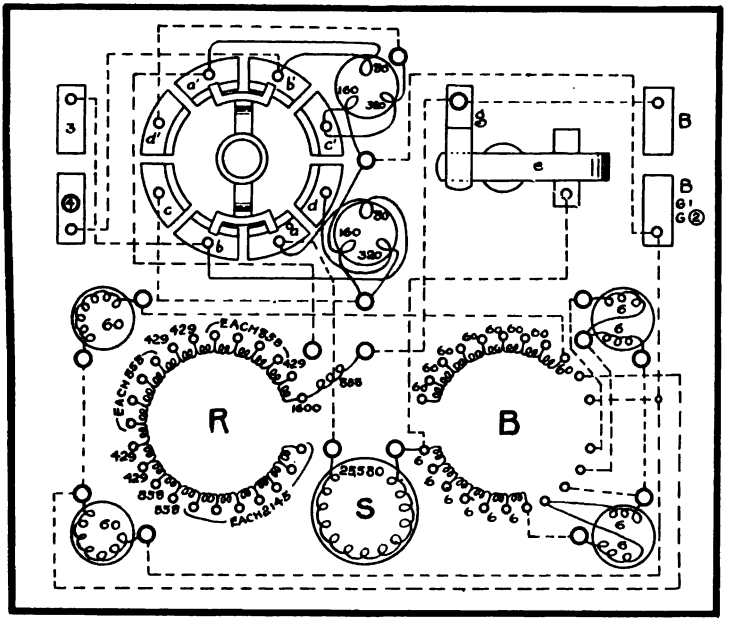

Fig. 53.—Internal connections of the Eden Battery testing instrument.

from the introduction of 429ω per cell is reduced to $\frac{2}{3}$ a deflection of 100 divisions will again result.

The resistance of one coil of the galvanometer is 160ω, and this amount must of course be deducted from the resistance inserted with the cells under test. In order that the application of the shunt shall not vitiate the test by reducing the resistance of the circuit compensating resistances are employed.

Bichromate test—

$$\text{Shunt} = \frac{160}{2-1} = 160^{\omega}$$

$$\text{Compensating resistance} = 160 - \frac{160}{2} = 80^{\omega}$$

Leclanché test (80^{ω} added to galvanometer circuit)—

$$\text{Shunt} = \frac{240}{1\frac{1}{2}-1} = 480^{\omega}$$

$$\text{Compensating resistance} = 160 - \frac{240}{1\frac{1}{2}} = 0.$$

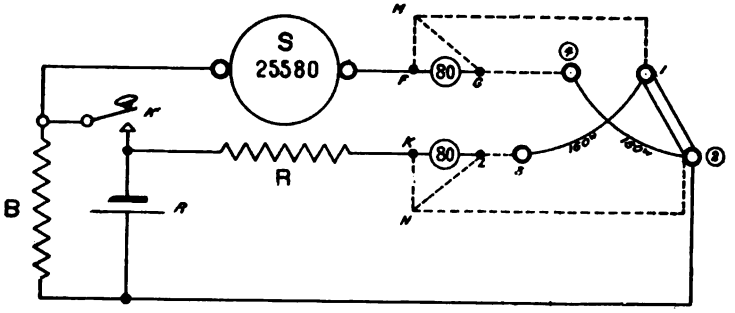

Fig. 54.—Principle of Eden Battery testing instrument.

Thus, by adding 80^{ω} to the galvanometer and shunting this combination by 480^{ω}, the value of the deflection is reduced to $\frac{2}{3}$ of its unshunted value and the joint resistance of the whole arrangement is 160^{ω}.

The complete connections of the instrument itself are shown in Fig. 53. The radial arm of the rheostat R is placed opposite the number of cells under test and inserts that many times 429^{ω} less the resistance of the galvanometer (160^{ω}). There are 23 points marked 0, 5, 6, 8, 10, 12, 14, 16, 18, 20, 21, 24, 25, 26, 28, 30, 35, 40, 45, 50, 55, and 60 cells. To the point marked "5" there is a resistance of 1985^{ω} ($429 \times 5 - 160$); to the next point 429^{ω}, and so on in coils of 429^{ω}, 858^{ω}, or 2145^{ω} according to whether the next point is 1, 2 or 5 cells in advance of

the last. It should be noticed that resistance is inserted *before* the first point on the rheostat.

Since the internal resistance test employs both coils of the galvanometer a set of shunts is provided for each coil. These shunts are controlled by a three-position switch, the positions of which are respectively marked "Dan.," "Lec.," and "Bic." In the first position the galvanometer is unshunted, whilst in the second, the 160Ω and 320Ω coils are joined in series across the 80Ω coil and galvanometer (Fig. 54). In the third position the 160Ω coil is placed directly across the galvanometer coil with 80Ω in the direct circuit. The upper half of the switch and the upper set of 80Ω, 160Ω, 320Ω coils are in connection with the 3-1 coil and the lower half with the 4-circle—2-circle coil.

Internal Resistance Test.

The fundamental principle upon which the test for internal resistance is based may be stated as follows:—

The current which a battery sends through a given resistance (R) is equal to the *total* current flowing through the given resistance (R) plus that flowing through a shunt (S) upon it, if the battery is also shunted by a resistance (B) which bears the same ratio to the internal resistance (r) of the battery that the shunt (S) bears to the given resistance (R). That is, if the current flowing through R is equal to the sum of the currents flowing through R and S when the battery is shunted, then:—

$$S : R :: B : r$$

A numerical example will serve to make the relation apparent. A battery having an internal resistance of 50Ω, is connected to a path having a resistance of 1000Ω. If the 1000Ω path is shunted by 2000Ω, the sum of the currents in these paths will be equal to the current through the simple 1000Ω circuit, if the battery is also shunted by a resistance of 100Ω:—

$$S : R :: B : r$$
$$i.e.\ 2000 : 1000 :: 100 : 50$$

Therefore the total value of the currents passing through

S and R is equal to that through R when the battery is unshunted.

Proof of Principle.

The principle, which has been laid down, may be proved to be true by taking a numerical example and applying the laws governing joint resistance and division of current enunciated in Chapter II. The following example gives the conditions existing when a battery of 20 Daniell cells each having an E.M.F. of 1·08 volts and an internal resistance of 3ω is tested by the instrument.

Example.—Show that the current through a resistance of 8580ω from a battery having an E.M.F. of 21·6 volts and an internal resistance of 60ω is equal to that flowing through 8580ω shunted by 25,740ω if the battery is also shunted by 180ω.

$$25740 : 8580 :: 180 : 60$$

1st condition. Current through $8580^{\omega} = \dfrac{21{\cdot}6}{8580 + 60}$

$= 2\frac{1}{2}$ m.a.

2nd condition. The circuits may clearly be regarded as consisting of the battery joined to 180ω, 8580ω, and 25,740ω in parallel, and therefore :—

Joint resistance $= \dfrac{1}{\frac{1}{180} + \frac{1}{8580} + \frac{1}{25{,}740}}$

$= \dfrac{1}{\frac{429 + 9 + 3}{77{,}220}} = \dfrac{8580}{49}$ ohms

Total current $= \dfrac{21{\cdot}6}{\frac{8580}{49} + 60} = \dfrac{147}{1600}$ amperes

Current through $8580^{\omega} = \dfrac{9}{441}$ of $\dfrac{147}{1600} = \dfrac{3}{1600}$ amperes

Current through $25{,}740^{\omega} = \dfrac{3}{441}$ of $\dfrac{147}{1600} = \dfrac{1}{1600}$ amperes

Total current through 8580ω and 25,740ω $= \dfrac{4}{1600} = 2\frac{1}{2}$ m.a.

This is the value of the current through 8580$^{\omega}$ with the unshunted battery, and therefore the truth of the principle has been demonstrated in this particular instance. By taking other examples, or by the aid of algebra, the truth of the general relation may readily be proved.

With the battery testing instruments the value of the E.M.F. deflection is first observed, and then a key is depressed which simultaneously shunts the battery and the resistance in series with the battery. The resistance of the battery shunt is next altered by moving the radial arms until the depression of the plunger leaves the value of the E.M.F. deflection unchanged. The arrangements are conventionally depicted in Fig. 54. The E.M.F. deflection is obtained through R (adjusted to the number of cells under test), and the 3-1 coil of the galvanometer. If Daniell cells are being tested KL is short circuited and N_2-circle cut, Leclanché cells 80$^{\omega}$ is joined between K and L with 480$^{\omega}$ joined between N and the junction of the coils. The other coil of the galvanometer is similarly shunted, according to the type of battery under test.

When the plunger K is depressed, the battery r is shunted by B, and the resistance R by the coil S. Now the galvanometer is so joined up as to indicate the sum of the currents through R and S. When the depression of the plunger leaves the value of the deflection unaltered

$$(S + 160) : (R + 160) :: B : r$$

The 160$^{\omega}$ added to each resistance is, of course, that of the one coil of the galvanometer which is included in each circuit. Now R is equal to 428$^{\omega}$ multiplied by the number of cells under test (n) whilst S is made equal to 60 times 429. The total internal resistance (r) of the battery is also proportional to the number of cells tested. Since the shunting power of the fixed resistance S upon R is proportional to the number of cells under test, whilst the shunting power of B with respect to r is also proportional to the number of cells under test, it will be seen that B does not depend upon the number of cells tested. The proportion may be written :—

$$(R + 160) : (S + 160) :: r : B$$
$$i.e.\ (n \times 429) : (60 \times 429) :: n \times r_1 : B$$

$$\therefore B = \frac{60 \times 429 \times n \times r_1}{n \times 429}$$

$$i.e.\ B = 60 \times r_1$$

In other words, the resistance of the battery shunt to produce equality of deflection is always equal to sixty times the resistance per cell, and is quite independent of the number of cells under test.

Example.—Show that the resistance of the battery shunt to obtain a balance is sixty times the resistance per cell (*a*) when 20 Daniell cells having a total resistance of 60$^{\omega}$; (*b*) when 60 Daniell cells having a total resistance of 300$^{\omega}$, are tested.

(*a*) $(R + 160) = 20 \times 429 = 8580^{\omega}$

$(S + 160) = 25{,}740^{\omega}$

$25{,}740 : 8580 :: B : 60$

$8{,}580 : 25{,}740 :: 60 : B$

$$\therefore B = \frac{25{,}740 \times 60}{8580} = 180^{\omega}$$

which is sixty times the resistance per cell.

(*b*) $(R + 160) = 60 \times 429 = 27{,}740$

$(S + 160) = 25{,}740$

$25{,}740 : 25{,}740 :: B : 300$

$\therefore B = 300^{\omega}$, which is $60 \times r_1$.

If therefore a series of 60$^{\omega}$ coils is provided so that 1, 2, 3, 4, etc., of these coils may be included in the circuit at will, and these points are marked 1$^{\omega}$, 2$^{\omega}$, 3$^{\omega}$, 4$^{\omega}$, etc., it will be evident that the internal resistance per cell of the battery under test may at once be read off from the position of the arm. If also a series of 6$^{\omega}$ coils is provided, the resistance of the cells may be read off to tenths of an ohm per cell.

Referring again to Fig. 53, it will be seen that the rheostat *B* contains ten 6$^{\omega}$ and ten 60$^{\omega}$ coils, thus enabling *B* to assume any resistance from 6$^{\omega}$ (corresponding to ·1$^{\omega}$ per cell) up to 660$^{\omega}$ (corresponding to 11$^{\omega}$ per cell). In this way the resistance of any battery may be found to the tenth of an ohm. For instance, a resistance of 4·7$^{\omega}$ would require $4 \times 60^{\omega} + 7 \times 6^{\omega} = 282^{\omega}$ for *B*, the upper radial arm of *B* thus being placed at 4, and the lower at ·7.

In Fig. 53 it will be observed that the first four 6$^{\omega}$ and the first two 60$^{\omega}$ coils are shown separately. These coils are of much thicker wire than the remainder, so that, when cells of low internal resistance are tested, the resulting heavy currents may not cause undue heating. It will also be evident that the radial arms should always be kept in the extreme positions corresponding to maximum resistance (11$^{\omega}$) and maximum number of cells tested (60). Serious heating of the coils would result if this precaution were not taken. Dry cells should not be tested by the instrument on account of their very low internal resistance and the large currents which would result during the resistance test. The difficulty may be obviated to some

FIG. 55.—Eden Battery testing instrument.

extent by placing R at four or five times the number of cells actually under test, and then dividing the result by 4 or 5 as the case may be.

The accuracy of the E.M.F. deflection depends upon the accuracy of the constant of the galvanometer, and before any tests are made the standard cell should be employed in the usual manner to obtain the constant.

The external appearance of the instrument is illustrated by Fig. 55.

BATTERY TESTING BOARD.

The connections of this instrument are shown in skeleton in Fig. 56 and in detail in Fig. 57. The radial arm

rheostats are replaced by two six-plug resistance boxes, *B* and *R*. *R* consists of six coils marked 1, 2, 4, 8, 16, and 32 respectively. The resistance of the first coil is 269ω, and this cannot be plugged out of circuit, whilst the resistances of the remaining coils are 1, 2, 4, 8, 16, and 32 times 429ω. The number of cells to be tested, minus one,

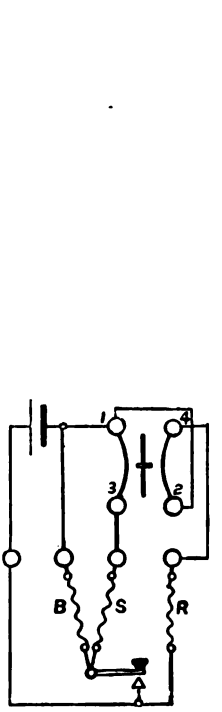

FIG. 56.—Principle of battery testing board.

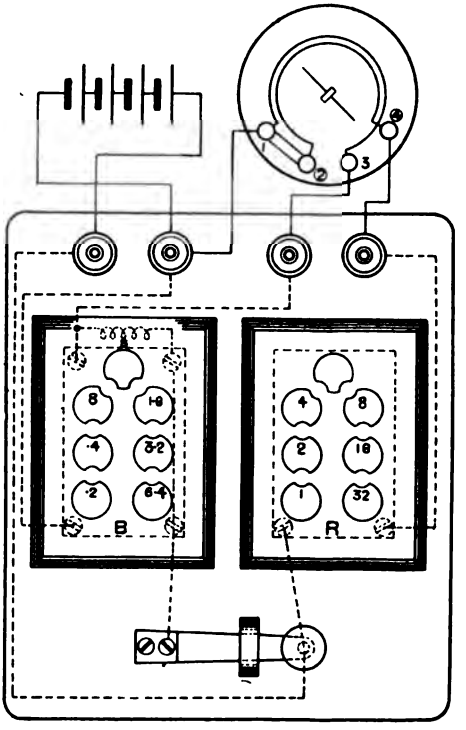

FIG. 57.—Battery testing board connections.

is unplugged in *R*. The battery shunt coils are marked ·2ω, ·4ω, ·8ω, 1·6ω, 3·2ω, and 6·4ω, and are wound to resistances of 12ω, 24ω, 48ω, 96ω, 192ω, and 384ω respectively.

As shunts are not employed the deflections obtained are 200, 150, and 100 with Bichromate, Leclanché and Daniell batteries respectively. The percentage fall is read in the

ordinary way in the case of Daniells, divided by two for Bichromates, and obtained from tables with Leclanché batteries.

The internal resistance is the sum of the resistances marked upon the blocks from which pegs have been removed to obtain a balance.

The principle of the test has already been fully dealt with in the case of the more complex instrument.

CHAPTER V

SINGLE CURRENT SYSTEMS AND RELAYS.

EARTH RETURN.

TWO conducting paths are required between the battery and the apparatus to be actuated by the current, in order that the circuit may be complete. For one of these paths the earth itself is employed, thus saving the extra cost, extra battery power and the extra liability to faults which the second wire entails. The earth return may be regarded as a perfect path having no resistance.

There are two theories in regard to the behaviour of the earth as a return current conductor. The first considers the earth a vast reservoir of electricity and therefore obviates the necessity of imagining that each current returns directly to its own battery. An analogy of a long pipe, with both ends dipping into the sea, and containing a rotary pump will serve to illustrate this theory. Imagine that the pipe is, say, ten miles long and that it is full of water. The pump is worked and water is picked up from the sea at one end and discharged back again at the other. Let the rate be, say, a gallon a minute. Every minute then sees one gallon of water picked up at one end of the pipe and a precisely equal quantity discharged at the other. Water momentarily accumulates in the sea at one end and its quantity is reduced at the other. The adjustment is one of general level between the two places, and it is therefore not a case of an identical gallon-a-minute stream going back through the sea in the same form that it passed through the pipe. So with an electric circuit; at one end electricity is continuously passed into the earth, and at the other continuously passes out in exactly equal quantity, the adjustment being one of level merely between the two ends of the circuit.

The second theory and probably the more correct one is that the current actually traverses the earth which, on account of the vast volume of material between the two plates, forms a path of practically no resistance. There are one or two difficulties which may at the outset be detailed and explained. Let there be three circuits working between Manchester and Liverpool and let two of these send 15 ma.s. *to* earth, whilst one is receiving 15 ma.s. *from* earth. Two currents in opposite directions cannot exist in one conductor at the same time, any more than two trains can travel between two places in opposite directions upon a single set of metals. It is therefore impossible to imagine that these currents in reverse directions cross each other. The explanation is that the batteries combine at the sending end, and it is only the balance of current which is conveyed by the earth. The

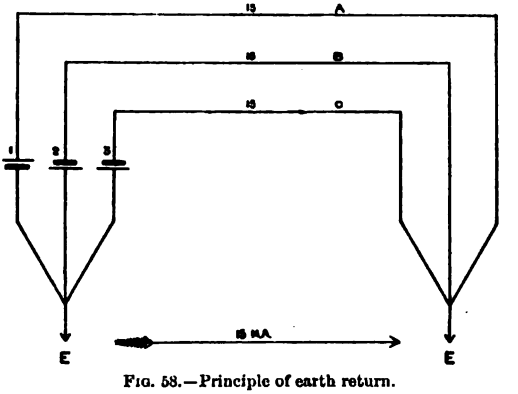

FIG. 58.—Principle of earth return.

conditions are shown clearly in Fig. 58. The current actually flowing through the earth is in this case 15 m.a. Batteries 1 and 2 may be imagined as connected in series to a circuit consisting of *A* as direct circuit, and *B* as return circuit also connected in series, and the earths entirely ignored. This argument gives precisely the same value of current in each circuit, but with opposite directions. The remaining battery sends its whole 15 m.a. via *C* and earth. This simple explanation, although illus-

trating the general principle, is not quite correct; the obvious objection being that there is no reason why battery 2 should combine with 1 rather than 3. The fact is that it combines with both. Batteries 2 and 3 each send $7\frac{1}{2}$ m.a. to earth, whilst the 15 m.a. going to the negative of 1 is made up of the remaining $7\frac{1}{2}$ m.a. from battery 2, and $7\frac{1}{2}$ m.a. from battery 3. A careful consideration of any required combination will show that the batteries combine in series as far as possible, and that the earth then conveys the balance of current.

At all large offices a very considerable number of circuits are always simultaneously sending and receiving currents of varying directions and magnitudes, and as these currents are all dealt with by the same earth connection, the truth of the explanations given above will be realized.*

Earth Connection.

The earth connection is made by sinking a galvanized iron plate 2′ 6″ square into the ground. Soldered to the plate is a stranded copper wire and to this the earth connection from the instruments is led. At a large office several plates are sunk and all are connected together in order to form a connection to earth of the least possible resistance. The plates should be sunk in damp ground, and where this cannot be obtained recourse must be had to neighbouring watercourses. At local offices the earth connection is often made by screwing a clip on the water pipes. If gas pipes are employed the connection should be made upon the road side of the meter. No earth which has a resistance exceeding 10^{ω} can be considered as efficient. For very large offices this figure is altogether too high, and, as previously mentioned, several separate earths are used.

Electromagnet.

Since iron conducts lines of force far better than air, the introduction of iron into the magnetic circuit or path of

* It is quite open to question whether any real difference exists between the two theories given. Using the analogy of the pipe and rotary pump it may be pointed out that, if the flow of water is very considerable, a strong current would set in between the ends of the pipe.

the lines of force greatly increases their number. In order to obtain a magnetic field of considerable strength, from a comparatively small current, it is necessary to have a large number of turns of wire and to introduce into the magnetic circuit as small an air-gap as possible.

An electromagnet and armature are conventionally

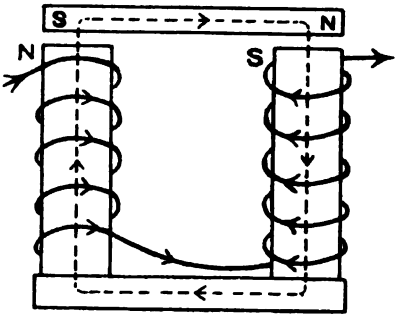

FIG. 59.—Magnetic circuit of a sounder.

depicted in Fig. 59, the path of the lines of force being indicated by the dotted line. In order that the circuit may be as shown, the polarities of the upper ends of the cores must be opposite in character—a result which is readily obtained by reversing the direction of winding in the case of the second core. Under the conditions illustrated in the figure, the top of the left core is North and the top of the right core South.

NORTH POLE OF SOLENOID.

The hand rule given upon page 10 shows how the direction in which the N. pole of a needle moves may be predicted when a current-conveying wire is placed above or below it. This rule applies in a similar fashion for finding the N. end of a solenoid. The right hand is placed round the solenoid so that the current is flowing in the direction of wrist to fingers, and the outstretched thumb will then indicate the north end of the solenoid.

The result of energizing the electromagnet is that the armature is attracted. This may be regarded as the result

of the tension along the lines of force which causes them to shorten by producing a downward movement of the armature. It may also be regarded from the point of view that the armature assumes an induced polarity as shown by the figure, and that attraction results.

Residual Magnetism and Retentivity.

Soft iron, more than any other material, is subject to residual magnetism; in the case of a very long rod or wire, it has been found that upon disconnecting the magnetizing current 93% of the magnetism remained. The smallest mechanical vibration or the use of an extremely small opposing magnetizing force, however, at once reduces the value of the residual magnetism to zero.

The explanation of the phenomenon may be deduced from the molecular theory (Appendix A.).

If a coil of wire is wound upon a continuous ring of iron and a current is passed through the windings the iron becomes magnetized. Upon cessation of the current the magnetism will still remain, because there is nothing which tends to demagnetize it. The molecules form a continuous chain around the ring. The lines of force are therefore circles inside the ring itself, and there are no external North and South poles. In order to demagnetize the ring it is necessary to disturb the closed chains of molecules, and this may be done by either a reverse current which reverses the direction of the magnetic field through the iron, or by shaking or hammering the iron and so disturbing the molecular chains. If now the ring is cut and straightened out it will be found that the iron becomes demagnetized immediately the current ceases, and that the amount of residual magnetism is enormously reduced. The reason is that the lines of force in this case have to pass from the North to the South pole of the iron through the badly conducting air. Demagnetization may legitimately be regarded as due to the attraction between the North and South poles of the magnet acting through the length of the magnetized iron. In the case of steel it has been remarked that this effect, even in very short lengths of steel, is not sufficiently great to produce demagnetization and the result is a permanent magnet. In order that

demagnetization may be rapid and complete an iron core should be as short as possible.

Applying this knowledge to the case of an electromagnet it will be seen that the nearer the conditions of the closed ring are reproduced the greater is the value of the magnetization which remains upon cessation of the current. When the armature is allowed to touch the cores no definite poles are created and there is little or no demagnetizing tendency, consequently the armature "sticks."

It is therefore essential that a small air-gap shall be left in order that demagnetization may be produced by the

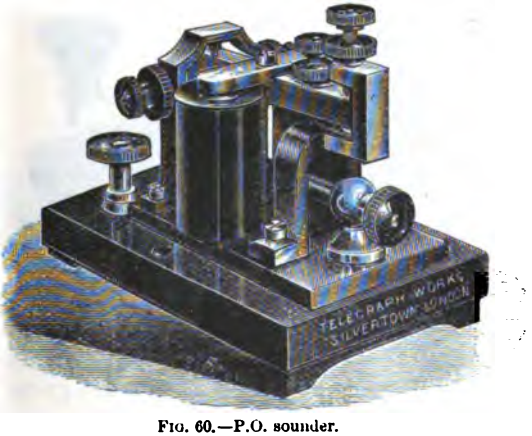

FIG. 60.—P.O. sounder.

action of the poles. It may also be remarked that the shorter the electro-magnet and the longer the air-gap the more rapid and complete is the demagnetization. With steel the values of the residual magnetism are not so large as with soft iron, but the demagnetizing tendency of the poles is quite insufficient to produce demagnetization. This fact is expressed by saying that the retentivity of steel far exceeds that of iron.

SOUNDER.

The Post Office pattern of sounder, shown in Fig. 60, consists of an electro-magnet with a soft iron armature

held away from its cores by an antagonistic spring. The tension upon this spring is adjusted by means of the screw supported upon the brass base of the instrument. The armature is fixed to the square and somewhat heavy brass bar which is carried upon a steel axle with pointed ends. The ends of the axle are held in the hollowed ends of two screws, one of which is clearly visible in the figure. The armature bar carries a transverse screw which determines the proximity of the armature, when depressed, to the cores. The clearance should always be at least equivalent to the thickness of a sheet of good notepaper in order to avoid

FIG. 61.—Single current key.

trouble due to residual magnetism. The screw immediately in front determines the amount of play to be given to the armature. It should be noticed that the armature adjustment and the axle screws are all four of them provided with a screwed washer, or clamping screw, which banks against the fixed portions. This serves to preserve the adjustments by preventing the screws from working loose.

Earlier forms of sounder were wound to a resistance of 40ω and a 500ω shunt was connected across its terminals, so reducing the joint resistance to 37ω. This gave way to one wound to 20ω with a 500ω shunt, *i.e.* 19·2ω joint resistance. This has now been abandoned in favour of a 21ω coil and 440ω shunt which together give a joint resistance of 20ω. Sounders for use in connection with secondary cell working are wound to a much higher resistance, but this point is dealt with in Chapter XV (page 462).

The figure of merit of the 37ω sounder is 55 m.a., that

of the 19·2ω sounder is 69 m.a., and that of the new 20ω is 55 m.a.

Single Current Key.

The single current key (Fig. 61) consists of a pivoted brass lever playing between two contacts, but normally held against the back contact by a spring. The under side of the lever in front is furnished with a platinum contact which, when the key is depressed, comes into contact with a similar stud fixed to the brass plate and

Fig. 62.—Single current galvanometer.

terminal. The back stop, so termed in contradistinction to the front stop, is also tipped with platinum and normally makes contact with the adjustable contact screw which passes through the lever. It should be noted that the lever is split from the end for a short distance, and that a screw is provided for tightening the grip upon the contact screw, thereby tending to preserve its adjustment. The tension adjustment is quite obvious.

Single Current Galvanometer.

The galvanometer employed is of what is officially designated the "single current" type. Its coils are wound

upon two bobbins, and in all the later forms its magnetic needle is of soft iron rendered magnetic by induction from permanent magnets. This arrangement avoids demagnetization of the needle by the passage of the working currents or by the portion of a lightning discharge which sometimes passes through the coils of the instrument. The arrangement is practically identical with the Varley type of single needle dial described later. Its general appearance is indicated in Fig. 62, from which it will be noted that the dial is not divided into degrees, but, instead, two ivory stop-pins are provided for limiting the range of the deflection. The two terminals of the instrument project horizontally from the back. The top of the needle deflects in the direction in which the current passes through the instrument. For example, if the current passes from the right to the left hand terminal the top of the needle moves over to the left. This rule applies to every form of galvanometer or needle dial employed by the Department.

The instrument has a resistance of 30Ω and a figure of merit of 9·3 m.a., with which current the needle should be deflected to either stop-pin. It is employed upon simplex circuits both single and double current, but not upon Wheatstone circuits.

Up and Down Stations.

Uniformity in connections is a most important matter on account of the difficulty of locating faults upon circuits which are not joined up according to a definite system. It is also desirable that all circuits fitted with the same type of apparatus should be joined up alike at the instrument tables. The connection of the set as a whole to line and earth differs at the ends of a circuit in order that the connections at the tables may not vary, and it becomes necessary to distinguish between the two ends of the circuit. One end is termed the up station and the other is called the down station. The station nearest to London is "up" and that furthest removed from London is "down." For example, London is the up station upon any London circuit. In the case of a Manchester-Newcastle circuit, Manchester is up and Newcastle down. It will be found that the up

station always connects the positive pole of the battery to the line when sending a marking current, hence the common phrase or statement that "the up station sends copper to line to mark."

Direct Sounder Connections.

A direct sounder set consists of a sounder, single current key, single current galvanometer, 5ω resistance coil, and battery. It is so termed because the received current makes the mark directly and not indirectly, *i. e.* by the aid of a relay. The right side of the galvanometer is the "down instrument terminal," and the junction of the sounder and negative pole of the battery is the "up instrument terminal." The apparatus connections are shown in Fig. 63, whence it will be seen that the down line passes through the galvanometer

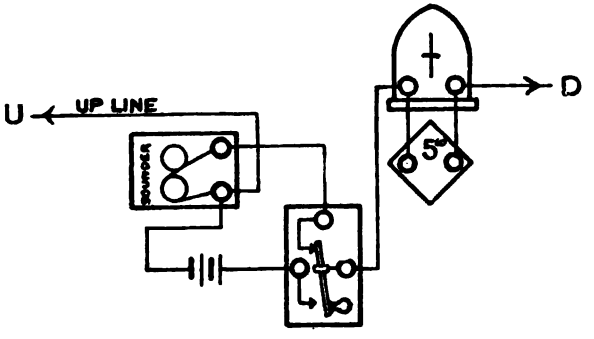

Fig. 63.—Direct sounder connections.

to the central point of the key. The key at rest affords a path *viâ* its backstop through the sounder to the up terminal. When depressed, the battery is connected positive to down and negative to up, the sounder being cut out of circuit by the severance of the connection between the key and the backstop. The galvanometer indicates the current sent or received. Its terminals are joined by a 5ω resistance coil for the purpose of reducing the resistance which its insertion unshunted would entail. As the current employed for working a direct sounder is very large the presence of the shunt does not prevent a satisfactory deflection being obtained.

Intermediate Stations.

The connections necessary to join up three sets upon a circuit are indicated in Fig. 64. At the up station the up line terminal of the set is earthed and the down line terminal is connected to the down line, *i. e.* the line to the down station. It is important that this fact should be clearly remembered because the statement applies to nearly every type of apparatus. At the intermediate station the down line terminal is connected to the down line and the up terminal to the up line. At the down station the down terminal goes to earth, whilst the up terminal goes to the up line. It will be noticed that at an up station the line is called a down line, whilst from the point of view of the down station it is an up line.

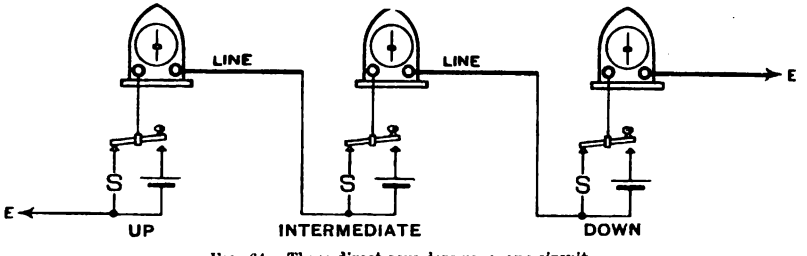

Fig. 64.—Three direct sounders upon one circuit.

Path of Current.

The path of the current when the intermediate station depresses his key is from the positive pole of his battery, to centre of key, through the galvanometer, along the down line, through the down sounder, along the key, through the down galvo, through earth, through the up sounder, along the key, through the up galvanometer, along the up line, back to the negative pole of the battery. Both sounders and all three galvanometers are affected. The path from the other stations is similar and should be sufficiently obvious. It may be remarked that the terms up and down line are employed above because the intermediate office was under consideration and the terms are relative to that office.

The current required to work a direct sounder circuit is

90 to 100 m.a. and large Daniells should be employed. The resistance of the galvanometer described on page 169 is 30ω, and with the 5ω shunt gives a joint resistance of $4\frac{1}{2}$ω. The direct sounder is employed where the total resistance of the circuit (apparatus included) does not exceed 200ω.

The Direct Writer.

The direct writer, printer, or inker, as it is variously termed, comprises an electromagnet with an armature

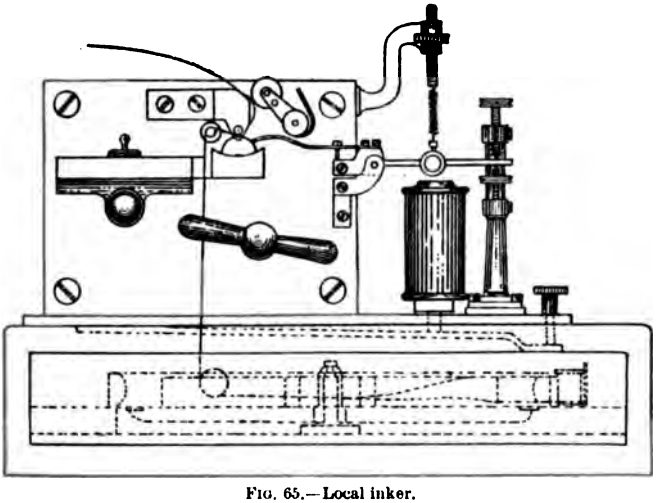

Fig. 65.—Local inker.

which, when actuated, causes a revolving disc immersed in an ink-well to be brought into contact with a paper tape moving at a uniform speed (see Fig. 65). The mechanical portion of the apparatus consists of a spring driving a train of wheels, which revolve the inking wheel in a direction opposite to that in which the tape is carried past it. The tape passes between two barrels, one of which is free to move and presses upon the tape, the other being revolved at a uniform speed by the train of wheels. A governor is employed for securing the uniformity of the rate at which the tape moves forward, and a brake is provided for stopping

the instrument when not in use. Two screws limit the play of the armature and inking disc in an upward and downward direction. These adjustments are made almost entirely from the point of view of securing clear inking marks whilst the sensitiveness is varied by a screw which bodily raises or lowers the electromagnet as a whole. The armature usually consists of a soft iron tube split longitudinally to prevent the instrument being rendered sluggish in action by reason of the eddy currents which would otherwise be induced in the armature. It is, however, open to question whether this provision is really necessary.

The connections of the direct writer (Fig. 66) are similar

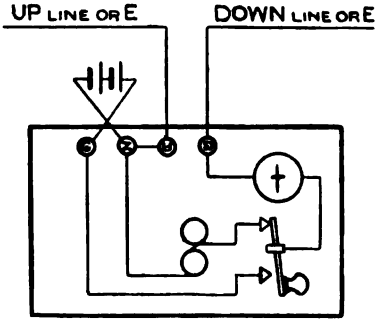

FIG. 66.—Direct writer connections.

to those of the direct sounder, but the battery and up and down line terminals are separately mounted upon the base of the instrument. The instrument illustrated in Fig. 65 is a local inker, and is sometimes used upon relay worked circuits. The direct writer is similar, but contains a key and galvanometer upon the same base. The connections between line and earth are determined in the manner previously detailed. The electrical portions call for no comment.

The resistance of the electromagnet of a direct writer is 300ω, and the galvanometer, which is of a simple form, about 30ω. The current required is from 15 to 20 m.a., and Daniell batteries are employed with it—formerly of the now obsolescent small type.

It should be noted that where a direct sounder is

employed at one end of a circuit and a direct writer at the other the battery power required will be different on account of the differing values of current required to work each form of instrument.

The figure of merit of the electromagnet is 4·9 m.a., and 10 m.a. for the galvanometer with which current a deflection of a quarter of an inch should be produced. The speed of the slip should be from six to seven feet per minute.

Open and Closed Circuit Working.

There are two methods of working circuits known as the open and closed circuit methods respectively. The former is almost exclusively employed in this country whilst the latter is in most extensive use in America. A circuit

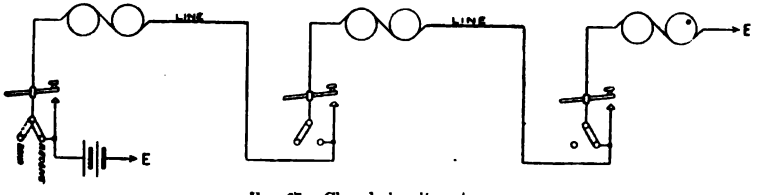

Fig. 67.—Closed circuit system.

worked upon the open method is one in which no current traverses the circuit when idle, and, as a corollary, batteries are needed at both ends. The direct sounder circuit may be taken as a typical example.

In the closed circuit system the current is normally flowing through the circuit when idle and signalling is effected by opening a two way switch, which permits the circuit to be made and broken in accordance with the movement of the key. The sounders are, of course, in the main circuit in series with the battery which may be located at either end of the circuit. The signals sent out are also received upon the instrument at the sending end. This appears to be a frequent device in America and it is contended that hearing the signals sent out makes for better sending. The objection to the closed system is the waste of power when the circuit is idle, but against this must be set the saving in the cost of maintaining batteries at

outlying offices. A similar arrangement has been adopted in connection with the metropolitan switching scheme briefly described in Chapter XIII.

The general arrangement of a closed circuit system is shown in Fig. 67, and affords a comparison with the open circuit system depicted in Fig. 64. Each key is provided with a switch, which is opened when it is desired to send. It will be seen that, in the conditions shown, the intermediate office is signalling. The arrangement is, however, sufficiently obvious.

THE SINGLE NEEDLE SYSTEM.

The single needle instrument, although contained in a single case, may be divided into two distinct parts, the commutator or transmitting keys and the coils. The coils are a special form of galvanometer, and serve to indicate the direction of the current. The commutator, when at rest, completes the circuit of the coils from line to earth, whilst the depression of a key puts the battery in circuit in a direction dependent upon which of the two keys is depressed.

The two coils of the instrument are of rectangular shape, placed side by side, and held in position upon the brass support by clamping screws. The coils are wrapped as closely round the needle as possible in order to concentrate the magnetic field produced by the current. This arrangement would not serve for the *measurement* of the relative strengths of different currents on account of the complexity and uncertainty of the relations existing between the value of the deflection and the current producing it. Where, however, it is merely desired to indicate the direction of a current and to require the minimum value of current to give a reasonable deflection, this form possesses the advantage of much greater sensitiveness.

The two patterns of needle coils in use at the present time are Varley's and Spagnoletti's, the latter being the later type. There is a very large number of Varley coils in use at the present time, although all new instruments are now fitted with Spagnoletti dials. The difference in the two types lies in the shape and in the method of rendering the needles magnetic by induction from fixed permanent

magnets. In the early forms of single needle the magnetic needle was a piece of magnetized steel, that is to say a permanent magnet. It was, however, soon found that the passage of the working currents in course of time weakened the small magnetic needle, and frequently after a thunder-storm the needle was even reversed in polarity by the small

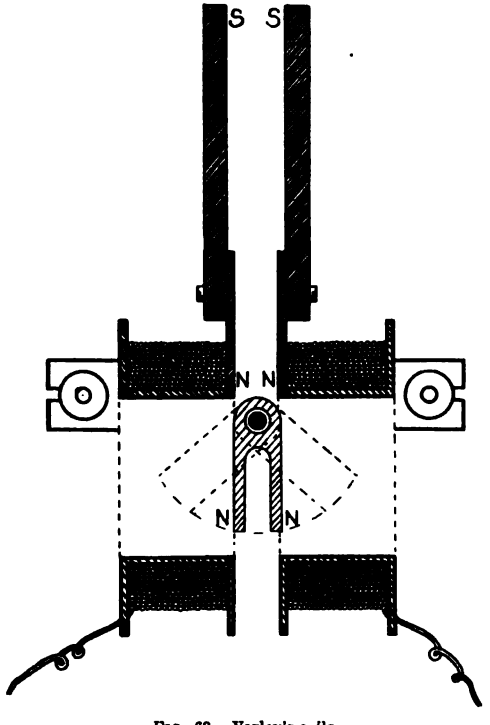

FIG. 68.—Varley's coils.

portion of the lightning discharge which sometimes passed through the coils. It was to avoid this difficulty that the induced needle was introduced.

VARLEY'S COILS.

In the Varley form the needle is a fork-shaped piece of soft

iron rendered magnetic by induction from a pair of comparatively large bar magnets fixed one upon each coil (Fig. 68). The magnetic needle is fixed upon an axle, which also carries the pointer, and it should be noted that the magnetic needle is suspended well above the centre of the coils. As the direction of the magnetic field due to the earth (vertical component) is in such a direction as to make the upper end of the soft iron needle South, and the lower end North, the permanent bar magnets are arranged so as to reinforce instead of oppose this effect. The upper or fixed end of the needle is therefore of South and the lower ends North

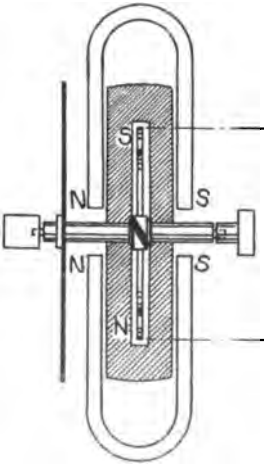

FIG. 69.—Side view of Spagnoletti's coils.

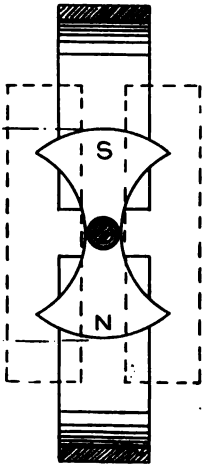

FIG. 70.—Illustrates the shape of the needle in Spagnoletti's coils.

polarity. The passage of a current through the coils creates a magnetic field through the centre spaces, and the needle deflects in accordance with the principles previously explained. In this case, however, the deflection of the needle is opposed by the earth's *vertical* field (which is larger than its horizontal field), and also by gravity.

SPAGNOLETTI'S COILS.

The Spagnoletti dial (Figs. 69 and 70) is fitted with two coils clamped in position in the same manner as in the

Varley type, but here the resemblance ends. A pair of horse-shoe magnets is employed for inducing the soft iron needle, which is made in two sections magnetically separated by the layer of spelter which serves to braze them together. The two magnets, each of which pass over the coil from back to front, have their like poles opposite. The soft iron axle extends in a downward direction to form the lower half of the needle, which end is given North polarity by induction of the two North poles of the horse-shoe magnets upon the front part of the axle. In similar manner the upper end of the needle is made South. This needle is given a somewhat curious shape in order to secure a firmer impact upon the stop pins, or sounding pieces as the case may be. The needle is also better balanced than in the Varley form. Similar remarks in regard to the direction of the current and the resulting deflection apply in this case also. A current from left to right causes the needle top to deflect to the right.

One end of each coil is connected to the brass bobbin upon which it is wound, and the other end is brought out to its terminal by a stout piece of spirally coiled silk-covered wire. There is therefore only one exposed wire connection for each coil. The current of course passes along the brass frame from one coil to the other.

These large horse-shoe magnets retain their magnetism for a very long period of time, in spite of the passage of the working signals. The demagnetization or reversal of the magnets by a lightning discharge is a very remote possibility, and one which need not in this case be seriously considered. The arrangement is, therefore, an excellent one.

Figure of Merit.

The coils are wound to a resistance of 200$^{\omega}$, and have a figure of merit of 3·06 m.a. with which the needle should be deflected from a vertical position to either stop pin. Good working signals can be obtained with 9·3 m.a.

In order to transform the needle from visual to sound working, the stop pins are replaced by two pieces of specially shaped tin so arranged that the impact of the needle produces two differing sounds according to the direction of its deflection. This amply suffices for the majority of sub-

offices, but where a greater volume of sound is required Neale's acoustic dial is very frequently employed.

Neale's Coils.

Neale's dial (Fig. 71) consists of an electromagnet having

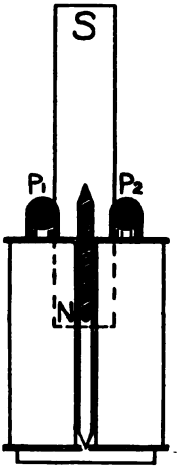

Fig. 71.—Neale's coils. Electromagnet and induced needle.

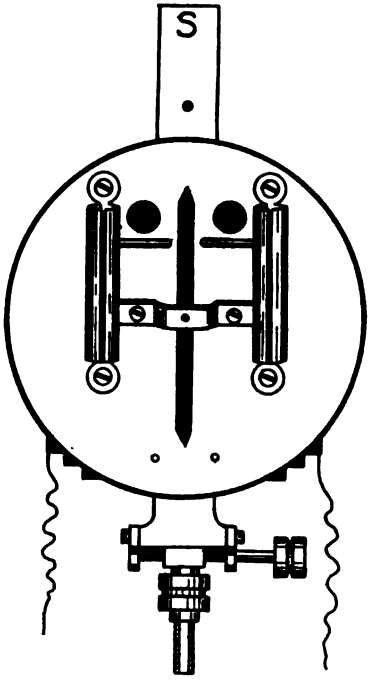

Fig. 72.—Front view of Neale's coils.

its pole-pieces P_1 and P_2 continued through the front of the dial, between which is pivoted a heavy soft iron needle rendered magnetic by induction from a curved permanent magnet $N S$ placed at the back. The heavy upper half of the needle is of soft iron, whilst the lower part serves only to complete the needle, and is quite light in comparison with the other. The axle which holds the needle is provided with a small hook to which is attached a light spiral spring

for the purpose of bringing the needle back after deflection. The other end of this spring is fixed upon a carriage (Fig. 72) which may be moved laterally by a screw upon the right, thus enabling the needle to be centred between its pole-pieces. The sounding pieces consist of tubes cut longitudinally and provided with extension pins upon which the needle strikes.

The use of an electromagnet in place of the coil of wire employed in the ordinary forms of needle dial gives a greater impact with the same value of current. This is entirely due to the use of iron and consequent improvement of the magnetic circuit.

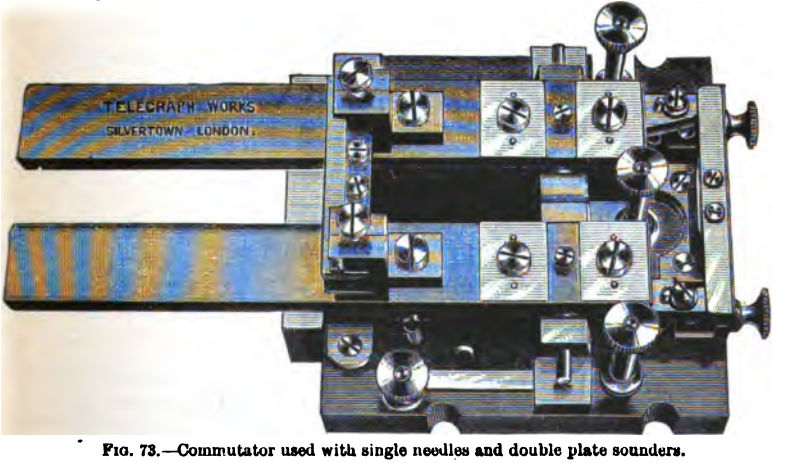

FIG. 73.—Commutator used with single needles and double plate sounders.

COMMUTATOR.

The general appearance of the commutator is shown in Fig. 73, and it is most important that the various parts of the actual apparatus should be identified with the sketch of their connections. Unfortunately it is not possible to draw the key as it appears to the eye, and at the same time clearly show its internal connections.

The commutator is furnished with six terminals, but when used in conjunction with the single needle two of these, *X* and *Y*, are permanently connected by a brass strap. These two terminals project horizontally at the back, and

are connected to the backstops of the keys to which they are respectively opposite. The two outer terminals in front of *X* and *Y* are respectively connected to *Z* and *C* of the battery. The centre terminal *B* may be considered as the down line of the key, whilst the short front terminal *A* is always the up line terminal.

Each key is electrically divided into two parts, viz. the brass lever at the back and the front contact screw. The

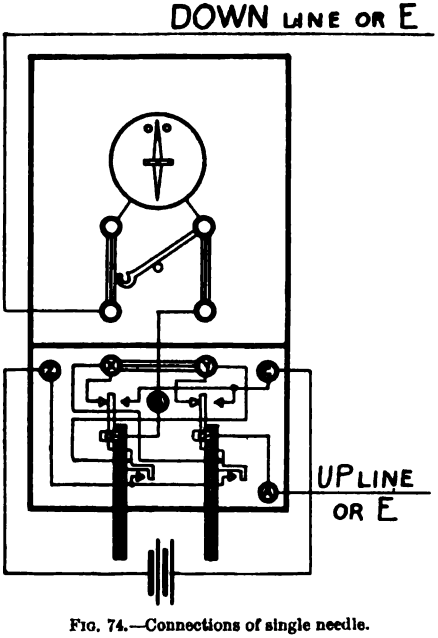

FIG. 74.—Connections of single needle.

wooden part of the key is fixed to the brass lever, and the front contact screw is fixed to the wooden key itself. Upon depressing the key the front contact screw comes into contact with the "zinc spring," and the brass lever at the back rises from the back stop and makes connection with the "copper spring." The terms zinc and copper springs are expressive, and should tend to fix the functions of the various parts of the key in the memory. The right-

hand brass lever is connected to the up line terminal, whilst the left goes to *B*. The only connections remaining to be dealt with are those of the front contact screws. These go to *X* and *Y*, the left to *Y* on the right, and the right to *X* on the left. This connection is made by the spiral of bare wire (see the right key) through the base of the instrument, these two connections being the only ones which the base conceals.

The connections are conventionally shown in Fig. 74. The keys are turned upon their sides, and movement to the left is equivalent to depression. The two contacts upon the right of the levers represent the copper bar whilst the two front contacts represent the zinc bar.

In the normal position a current entering at the up line terminal (usually marked *A*) goes to the centre of the right

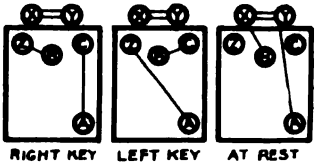

FIG. 75.—Skeleton connections resulting in each position of the keys.

lever along its length through the *Y* backstop to *Y* along the connecting bar to *X*, through the *X* backstop down the left lever to *B*. The connections are therefore *A* to *Y* and *B* to *X* through the two backstops.

Depression of the right key causes the right lever to break with *Y*, and to make contact with the copper spring, whilst its front contact screw makes contact with the zinc bar. The positive pole of the battery is therefore connected to *A* and the negative to *X*, through the *X* backstop, along the left key to *B*. The connections are therefore *C* to *A* and *Z* to *B*.

The left key when depressed causes the left lever to break connection with the *X* backstop, and to make contact with the copper spring, so connecting *C* to *B*. At the same time the front contact screw makes contact with the zinc spring, thus connecting *Z* to *Y*, through the *Y* backstop

down the right lever to *A*. The connections are therefore *Z* to *A* and *C* to *B*.

Each contact point is, of course, tipped with platinum. The play of the key is regulated by means of the front contact screw, which is securely held by means of the transverse screw, seen upon the right key in Fig. 73. (Compare also Fig. 61.)

Skeleton Connections of Commutator.

The skeleton connections in each position of the keys, shown in Fig. 75, should be memorized. The following facts may perhaps be useful—(*a*) Right key sends copper to up line, (*b*) at rest *A* and *B* go respectively to *X* and *Y*.

Connections of Single Needle Circuits.

The commutator and the dial are joined up in series so that every current which is sent out passes through the sender's instrument. The right-hand side of the coils is joined to *B* whilst the left side forms the down line terminal of the set, *A* being the up line terminal. To prove the connections, the up and down terminals of the set should be connected. Remembering that the right key sends copper to up and that the deflection is in the direction of the current through the coils it will at once be seen that *B* must go to the right (see Fig. 74) of the coils in order that the current may go through from right to left when the right key is down.

Three offices connected by two lengths of line are illustrated in Fig. 76, and the up and down instrument terminals have been clearly indicated. The joining-up of the set then follows the rules laid down in the case of the direct sounder.

(1) Up station, up line terminal to earth, down line terminal to down line.

(2) Down station, down line terminal to earth, up line terminal to up line.

(3) Intermediate station, up line terminal to up line, down line terminal to down line.

The path of the current and its effects in any given position of any of the keys is fairly obvious, and one example will suffice. Let the intermediate station depress

the right key; the current flows from the positive pole of the battery, to up line terminal, to line through the up dial (left to right therefore deflecting it to right) to *B*, to *X*, to *Y*, to *A* (up line terminal), through earth to down line terminal of down set through the dial (deflects to right) to *X*, to *Y*, to *A*, along the line, through the intermediate station's coils (needle deflected to right) to *B*, to *Z* and so back to the battery.

Resistance and Battery Power.

The resistance of the instrument is always 200$^{\omega}$, no matter which type of dial is employed, and a current of

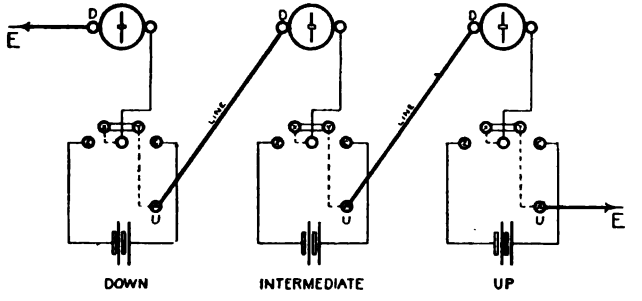

Fig. 76.—Three single needle stations upon one circuit.

from 15 to 20 m.a. is provided for actual working. The type of cell employed to work such circuits is the Leclanché No. 3 size.

Advantages of System.

The single needle system presents the advantage that many offices may be grouped upon a single circuit. Upon such circuits the value of the current received at any one of the offices may differ according to which office is sending. This is, of course, especially noticeable upon long circuits due to changes in insulation resistance, but as the system is rarely employed on any but short circuits, this difficulty does not assume serious dimensions. Another cause producing variations in the value of the received current is the condition of the various batteries; at one office

the battery may be at its maximum E.M.F., at another it may be at the minimum, whilst the batteries at the remaining offices are in conditions which respectively vary between the two limits. The reason for the excellent behaviour of a single needle system under such conditions lies in the fact that residual magnetism does not come into play.

Tracing Instrument Faults.

In tracing faults it is best to get as many facts together as possible, and so reduce the area to be searched to the lowest possible limits. In a simple piece of apparatus such as the single needle the location of a fault is quite easy, but with more complicated apparatus a definite system is essential. The tracing of the effect of every possible fault in a simple case will, however, prove both instructive and practically valuable.

The contact points are always the most likely places for faults. If either of the front contact screws fail to make contact when the copper spring and lever is doing so or *vice versa*, no current will be sent out by the faulty key. This would be observed upon the sender's instrument. The distant station's signals would, however, be received correctly. If neither key sends out a current then the battery is probably disconnected or short circuited. Again, if only one key sends out a current one pole of the battery may be to earth.

A dirty backstop prevents reception altogether, but permits that particular key to send out a current whilst preventing the other key from doing so.

Disconnection of the coils or parts of the circuit common to both sending and receiving paths stops working altogether. The apparatus may always be proved by joining *A* and the down line terminal by a wire, and observing if the needle is deflected by each key in turn.

RELAYS.

A relay may be defined as an electromagnetic device which either forms or breaks an electrical connection by the motion of its moving system produced by the passage of a current through its coils. Its prime purpose in tele-

graphy is to economize battery power, thereby obviating the use of extremely high voltages for working long circuits. The current is employed to direct and control the movement of a contact arm which joins up a battery at the receiving end of the circuit, and it is this battery which produces the actual signal.

Relays may be divided into two distinct classes (1) non-polarized and (2) polarized. In a non-polarized relay the direction in which the armature or armatures move is independent of the direction of the current passing through its coils.

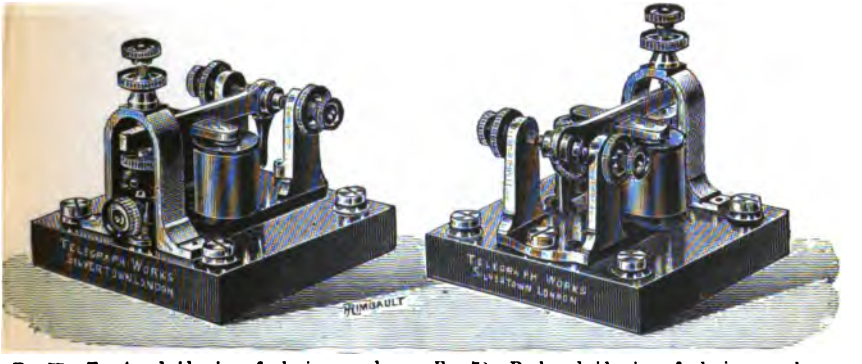

FIG. 77.—Front and side view of relaying sounder. FIG. 78.—Back and side view of relaying sounder.

RELAYING SOUNDER.

An example of such a relay is the relaying sounder (formerly termed an uprighter or uprighting sounder). This instrument is typical of the many varying forms which the non-polarized relay takes under different circumstances.

The relaying sounder consists of an electromagnet with its armature mounted upon a brass lever playing between an upper and lower contact point. It differs from an ordinary sounder in the shortness of its electromagnet, in the lightness of the armature lever, and in the provision of the platinum tipped contact points. The proximity of the armature to the cores when the former is depressed, may be adjusted by means of the lower contact screw which can be raised or lowered as required. The upward play is

similarly adjusted by the upper contact screw, whilst the tension may be suitably varied by the screw which is to be seen at the front of Fig. 77.

Normally the lever joins the upper contact, but when actuated, the lower one. A current in either direction, provided it be of sufficient strength, draws down the armature.

The coils and shunt of the "relaying sounder B" have resistances of 40ω and 500ω respectively. The figure of merit is 69 m.a. and the combined resistance 37ω. The latest type of instrument has a joint resistance of 40ω and

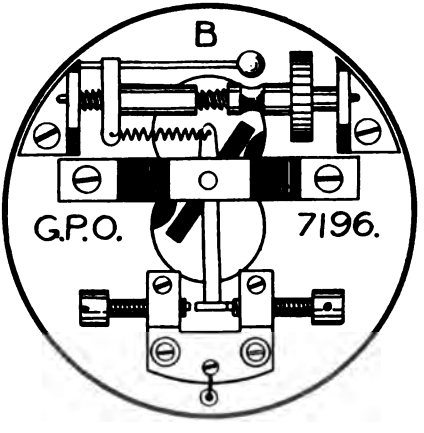

FIG. 79.—Top of a P.O. non-polarized relay "B."

is termed the "relaying sounder 40ω." Its coils and shunt are respectively 44ω and 440ω. It may be added that the object of the shunt is to prevent sparking at the relay points (see page 202).

P.O. NON-POLARIZED RELAY "B."

The Post Office non-polarized relay "B" bears a considerable resemblance to the standard relay (see Figs. 82 and 84), but its two soft iron armatures are not induced magnets. The two electromagnets are placed side by side, but with their polepieces deflected so as to include the

armatures in the magnetic circuit from core to core. The arrangement will be sufficiently apparent from the plan of the top of the instrument (Fig. 79). The tongue is held to the right contact point by a spring, and a current passing through the coils in either direction causes the armatures to be attracted against the force of the spring, and the tongue leaves the right contact point and goes over to the left. This arrangement is adopted for quadruplex working, for the reasons given in Chapter VIII.

The relay is differentially wound and an equal current flowing from *D* to *U* in one coil and *U* to *D* in the other, or *vice versa*, does not magnetize the cores of the relay. A current flowing in either or both coils from *D* to *U* or *U* to *D* magnetizes both cores and attracts the armatures. If the top of the left core is North the top of the opposite core is South, and therefore the magnetic circuit is from core to core through both armatures. These armatures are each divided in the centre by a layer of spelter which brazes the two halves together. This device prevents the armatures from becoming more or less permanently magnetized, since the demagnetizing force in such short lengths of iron as the two halves of each armature is considerable (see page 166). Moreover, the proximity of the armature to the cores and the consequent reduction of the air-gaps produces conditions favourable for considerable values of residual magnetism, were it not for the magnetic separation of the armatures. These breaks in the magnetic circuit tend towards the production of rapid and complete demagnetization of the cores.

Relays used in Telephony.

The relays which form so important a part in a large telephone exchange differ very widely from those previously described, although belonging to the same class, viz. non-polarized relays. Relays used for telephone signalling are designed from the point of view of reliability, compactness, and minimum cost, rather than from the point of view of sensitiveness and rapidity of action. Many of the relays have gravity controlled armatures, whilst pivots are avoided by allowing the thinned edge of the armature to rest in a nick or cut upon the base of the instrument. Such a relay

is illustrated in Fig. 80, and it will be observed that the magnetic circuit is nearly closed. Since great rapidity of action is not required, this arrangement presents the advantage that the sensitiveness of the relay is thereby increased. The distance of the armature from the core

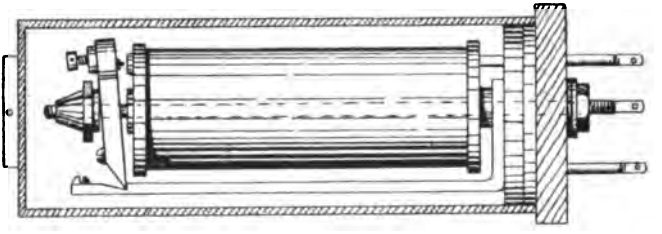

FIG. 80.—A type of relay used in telephone exchange systems and also in the Metropolitan intercommunication system.

when the relay is actuated is, of course, adjusted so that the relay shall not stick.

TRANSLATING RELAYS.

The relays (Fig. 81) employed in connection with the London switching system (Chap. XIII) upon the connecting cords are of practically the same pattern as those

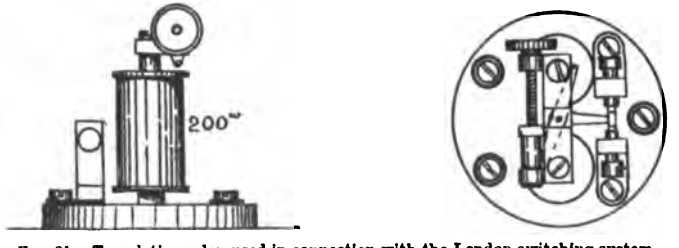

FIG. 81.—Translating relay used in connection with the London switching system.

formerly used in the telephone permanent current system. The two armatures are placed between the four polepieces of the electromagnet, and are controlled by an adjustable spiral spring. The resistance of the instrument is 200Ω.

It may be noticed that the armatures are solid, and are not divided by a layer of non-magnetic material, as is the

case with the relays used in quadruplex working. The dimensions of the various parts are also very much less.

Polarized Relay.

Polarized relays may be defined as relays in which the direction of movement of the tongue depends upon the direction of the current. It is necessary to avoid the very commonly used and inaccurate expression "only marks with one direction of current," because a mark is made by both directions of current when used with the double plate sounder (dash or dot according to the direction of the current).

Generally speaking, polarized are more sensitive than non-polarized relays. Also the armatures of non-polarized relays are usually unmagnetized soft iron, whilst those of polarized relays are either permanent or induced magnets. In other words, the armatures of non-polarized relays are not polarized, whilst those of polarized relays are.

P.O. Standard Relay.

The P.O. standard relay consists of two electromagnets placed side by side, between the poles of which are two movable soft iron armatures, rendered magnetic by induction from a large horse-shoe magnet placed behind them. The instrument is shown in Fig. 83 with one of its electromagnets removed, and in skeleton perspective in Fig. 82. The large horse-shoe magnet is bent round the coils so as to occupy the minimum space. For the reasons that obtained in the case of the inducing magnets employed in the single needle, the upper pole is South and the lower North. The corresponding polarity is therefore imparted to the ends of the soft iron armatures *s* and *n*. The axle which carries *s* and *n* also carries the contact arm, transversely tipped with platinum. Upon either side is fixed a platinum-tipped contact screw, and it is between these screws that the tongue plays.

The instrument is differentially wound, *D* and *U* being the terminals of one coil, and *D*-circle and *U*-circle those of the other. A current passing from *U* to *D* or *U*-circle to *D*-circle makes the top of the left electromagnet South and the bottom North, whilst the top and bottom of the right-

hand electromagnet are made respectively North and South. The armatures are therefore acted upon with four forces, being repelled by the left and attracted by right electromagnet. Reversal of the current reverses the direction in which the armatures tend to move. The two coils are equal in resistance, and with equal currents produce an equal effect upon the armatures. If a current is sent from *D*-circle to *U*-circle, whilst an equal one flows from *U* to *D*

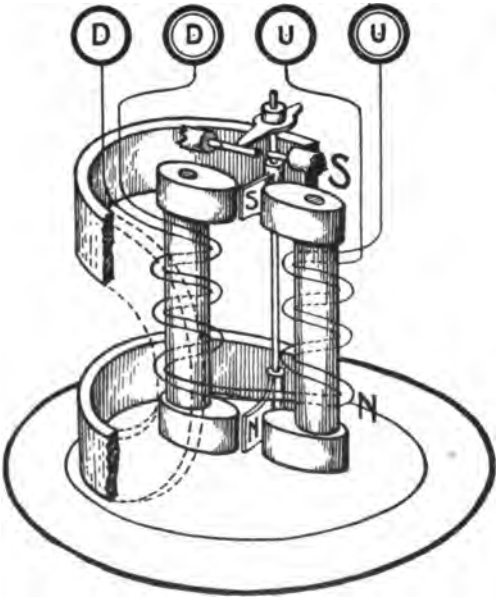

FIG. 82.—Principle of P.O. standard relay.

in the other coil, no effect is produced, since the two windings have an equal tendency to give the electromagnet opposite polarities.

The general arrangement and directions of the windings are clearly visible in Fig. 82. A current passing from *D* to *U* or *D*-circle to *U*-circle causes the armatures to be held over to the left, whilst a current in the opposite direction sends the armatures to the right. The disposition of the terminals is shown in Fig. 84, from which it

will be seen that a current from either *U* terminal to a *D* terminal causes *T* to make contact with *M*, whilst a current *D* to *U* brings *T* into contact with *S*. (*T*, *S*, and *M* are the first letters of the words tongue, space, and mark.)

The tongue of the relay when stationary always rests upon the *S* or *M* contacts, and never permanently in a central position. The two contact screws *S* and *M* are fixed upon a carriage which can be moved at will by means

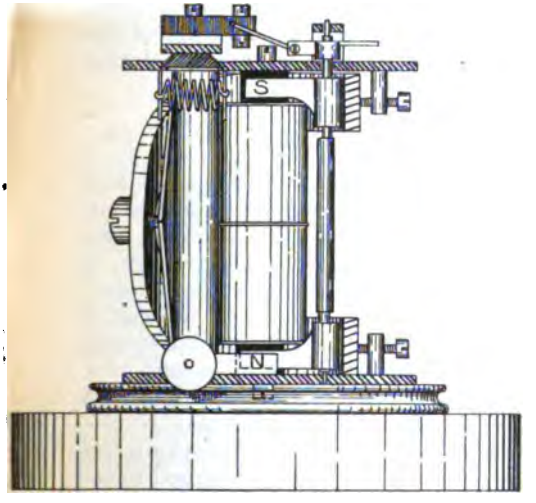

FIG. 83.—P.O. standard relay "B" (front coil removed).

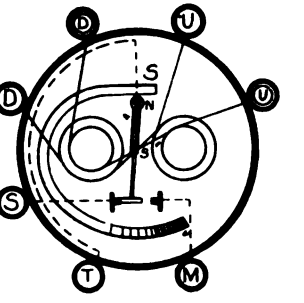

FIG. 84.—Winding and terminals of standard relay.

of the regulating screw. In this way the proximity of the armatures to either electromagnet may be varied. When the armatures are exactly midway between the polepieces if the tongue is held in a central position between *S* and *M*, the relay is said to be neutral, and the tongue will stay upon either side when placed there. When the armatures are placed in this central position the forces of attraction towards the polepieces upon either side are equal, but the balance is far too fine to be practically maintained. The moment the armatures move in the slightest degree the balance is upset and the armatures move over to the nearer side.

A relay which is not adjusted to neutrality is said to have a marking or a spacing bias as the case may be. A spacing bias means that the tongue will return to *S* after being moved over to *M* by the passage of a current. In that case it will be clear that even when deflected to *M* the *armatures* must be nearer to the left than to the right hand electromagnet. The most sensitive condition of the relay is when it has been set neutral, and the distance between *S* and *M* reduced to the smallest possible limits. Increasing the distance through which the tongue has to move reduces the working speed of the relay. The adjustments of the relay are therefore (1) bias, by means of the regulating screw; (2) play, by means of *S* and *M*.

P.O. Standard Neutral Relays.

For use in connection with double plate sounders, and in certain other cases where it is necessary to produce an effect in both directions by movement of the tongue, two spiral springs are added. These springs, which are of course adjustable and fixed at right angles to the tongue, serve to hold it in a central position midway between *S* and *M*. In another form of instrument a light flat spring is fixed upon the end of the tongue, and by means of a screw the length of the spring between the end of the tongue and the point at which it is clamped may be adjusted at will. The longer the length of this flat spring the smaller is the force with which the tongue is restored to its central position, and of course the greater is the sensitiveness of the arrangement. In the simpler double-plate sounder apparatus this device is preferable to the older spiral spring arrangement on account of the greater simplicity of adjustment, but for high-speed working experienced relay clerks usually prefer the older form on account of the superior fineness of adjustment which can be obtained.

Resistance and Figures of Merit.

Standard relays both ordinary and neutral are of two types, the older or "*A*" and the new "*B*" type. The *A* relay is rather shorter than the *B*, and its two coils are wound to 200$^{\omega}$ each, whilst those of the *B* type are wound to 100$^{\omega}$ each. The *B* relay has a lower resistance and a

lower self-inductance than the *A* type, whilst its figure of merit is the same, viz. ·5 m.a. (coils in series).

The resistance of the *A* relay in series, *i.e.* between *D* and *U*-circle, with *D*-circle and *U* strapped, is 400ω and in parallel, *i.e.* *D* and *D*-circle strapped, and *U* and *U*-circle strapped is 100ω. The values in the case of the *B* relay under like conditions are 200ω and 50ω respectively. To produce the same effect upon the tongues as 10 m.a. through one coil requires 5 m.a. through the two coils in series, or a total current of 10 m.a., *i.e.* five in each of the two coils when joined in parallel.

C Type Relays.

For multiplex working a much larger type of relay is employed, but in general arrangement it may be regarded as a large pattern standard relay. There is, however, the difference that the permanent or inducing magnet is arranged in a slightly different manner, and that it has a very light spiral spring attached to the tongue and adjustable by means of a long screw and carriage. The instrument is wound to a resistance of 1200ω (coils in series).

The non-polarized *C* relay which is now used for quadruplex working may be regarded as a non-polarized relay *B* of larger dimensions—equal, in fact, to those of the old multiplex relay.

It is found that by changing the design in this way some improvement can be effected in the resistance of the apparatus. The advantages gained thereby are dealt with in Chapter VIII.

Siemens Relay.

The Siemens relay is fast disappearing, but there is probably a fairly large number still in use upon short or local circuits. It consists (Figs. 85 and 86) of an electromagnet fitted with two adjustable polepieces between which plays an induced soft-iron armature. The permanent magnet passes under the yoke of the electromagnet, thus making both its limbs South at the top. The armature is of North polarity at the end, where it passes the two polepieces. The same remarks apply in regard to bias as those

made in the case of the standard relay. The passage of a current gives one core a stronger polarity, and the other a

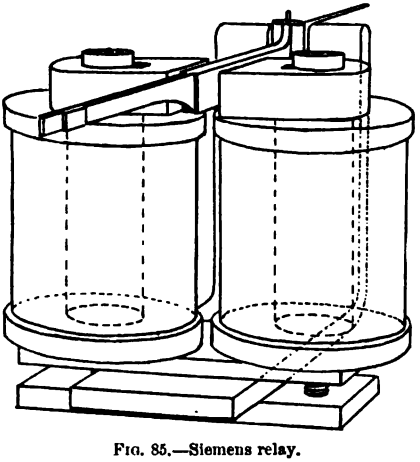

FIG. 85.—Siemens relay.

reduced or even reversed polarity. This causes the armature to move in a direction dependent upon the direction of the

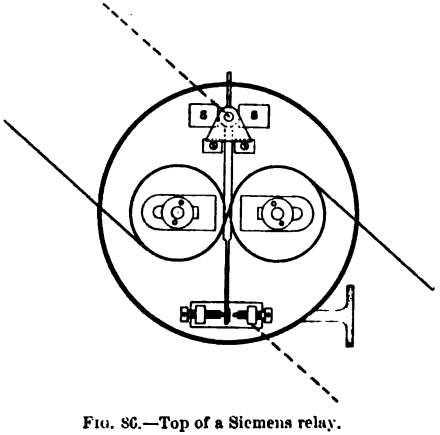

FIG. 86.—Top of a Siemens relay.

current. The terminals are arranged as in the case of the standard relay, but *S* is not usually provided.

It has the same resistance as the *A* relay, but it is not so sensitive (figure of merit 1·13 m.a.) and has a much larger self-inductance.

Test for Differentiality.

A relay is said to be differential when its two windings have exactly the same resistance, and have equal effects upon the cores when equal currents pass through them. The best test is obtained by joining up a battery and key to the relay, firstly between *D* and *D*-circle with *U* and *U*-circle strapped, thus placing the coils in series, but in such directions that the relay should not be magnetized, and secondly by joining the battery and key between *D*-circle and *U* strapped together, and *D* and *U*-circle joined, thus placing the coils in parallel. If the relay is then unaffected by working the key, the relay is differential.

In the first test, since the same current passed through the coils, it is proved that the windings have equal but opposite effects upon the cores with equal currents. The second test prove that the resistances of the two windings are equal, as otherwise one coil would carry more current than the other, and in view of the result of the first test would cause the relay to be affected.

Design of Relays.

In order to obtain rapidity of action, it has been shown that care must be taken to avoid large values of residual magnetism. This is accomplished by using iron of the softest possible description, and by arranging the magnetic circuit so that the molecular movements which produce magnetization and demagnetization are facilitated to the utmost extent, in other words by preventing the formation of anything which even approximates to a closed magnetic circuit.

It may be remarked *en passant* that the P.O. relay possesses the advantage of having two air gaps as opposed to the one in the Siemens relay. This should and no doubt does tend towards more rapid and complete demagnetization, but it is not the real reason for the superiority of the Post Office relay.

Where a relay is required for high-speed working, the

weight and the distribution of the weight of the moving system is of vital importance. A given force produces a movement the velocity of which is proportional to the moment of inertia of the moving system. Now the moment of inertia is the weight of every particle of the moving system multiplied by the *square* of its distance from the centre line of the pivot. In the Siemens relay the moving system is heavy, and what is far worse, extends far beyond the pivot. Compare this with the short armatures and light tongue of the Post Office relay, and the reason for greater rapidity of the newer instrument is at once apparent.

It will of course be quite obvious that for obtaining high speeds the angular movement of the tongue should be reduced to the lowest possible limits.

THE DOUBLE-PLATE SOUNDER.

The single needle, even when fitted with Neale's coils, proves unsatisfactory in any large instrument-room on account of the insufficient volume of the signals. Moreover the raised writing-desk renders it unsuitable for fixing upon tables along with sounder sets, but of course this could be remedied by altering the design. The double-plate sounder meets both these objections, whilst the simpler single needle may still be employed at the distant and intermediate stations.

The present type of instrument is the result of evolution with Bright's Bells as starting point. In this arrangement the increased volume of signal is secured by the use of a relay and local battery. The function of the received current is therefore merely to direct and control the movement of the relay tongue, and this in turn determines which of the plate sounders is to be actuated. The relay employed is of the Standard Neutral type fitted with springs which normally hold the tongue midway between S and M. A current passing through the relay in the direction U to D causes the tongue to move over to M, whilst a current in the reverse direction causes T and S to be joined. Between T and S is connected the "dot" sounder and local battery, whilst T and M are joined by the "dash" sounder with the local battery also included. The arrangement of

this circuit will be readily apprehended from a consideration of Fig. 87. When the tongue moves over to *S* the local battery sends a current through the left sounder, *S* contact point, along the tongue to *T'* and back to the battery. Upon cessation of the current the spiral springs return the tongue to its normal position midway between *S* and *M*. Similarly a movement of the tongue to the right energizes the "dash" sounder.

Plate Sounders.

The plate sounders each consist of an electromagnet and pivoted armature, normally held away from its cores by means of an adjustable spiral spring. The difference in the sounds produced by the two sounders is due to the difference in the material composing the two plates, one being of brass and the other of steel. The sounders are fixed upon the inner sides of a sounder-screen mounted upon a turn-table; the remaining details of their construction will no doubt be apparent from Fig. 88.

Commutator.

The commutator is of the same pattern as that employed in the case of the single needle, but it is joined up in a slightly different manner. It will be remembered that the depression of either key joins up the battery between *A* and *B* in a direction dependent upon which of the two keys is used. The received current passes along the *X Y* strap in the single needle, but in the double-plate sounder this strap is removed and the relay inserted. The single-needle dial is replaced by a single-current galvanometer, the left side of which forms the down line terminal of the set. The object of these alterations is to prevent the sent signals being received at the sending station and to provide an indication that currents are being sent out and received. Were the galvanometer not provided, a disconnection in the local circuit would pass undetected.

The objection to the reception of the signals at the sending end are the extra noise and the extra battery power necessary, against which no compensating gain in efficiency can be placed.

Connections.

The full connections of a double-plate sounder station are shown in Fig. 87. With a single-current galvanometer

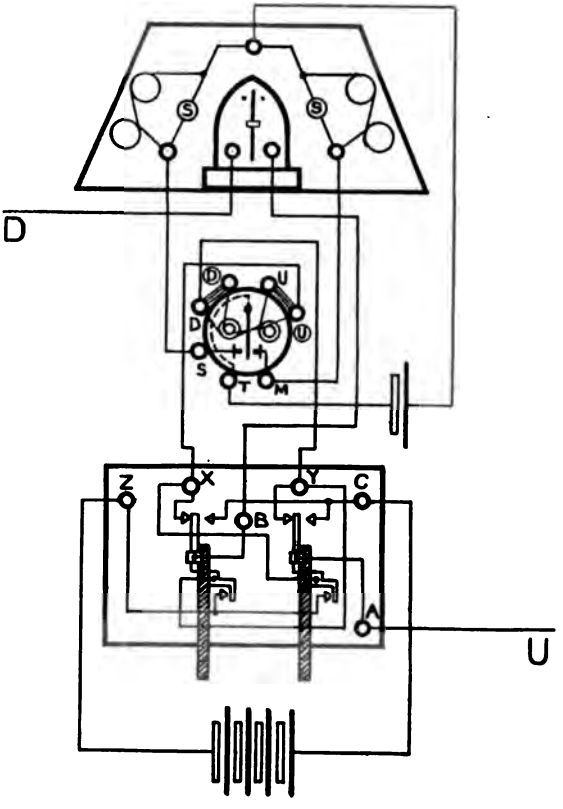

Fig. 87.—Connections of double-plate sounder.

substituted for the dial and X and Y unstrapped and respectively joined to U-circle and D of the relay the connections are identical with those of the single needle. It is useful to remember that the two connections between X and Y and the relay cross each other. A is the "up-line" terminal

and the left side of the galvanometer the "down line" terminal. At an up office the galvanometer (*D* terminal) is joined to line and *B* (*U* terminal) earthed, whilst at a down station the galvanometer is earthed, and *A* is joined to the line.

The path of the current upon depressing the right key is as follows:—From positive pole of the battery to the copper spring, along the right lever, to *A*, to earth, through earth and by distant apparatus to line, along the line back to the up station through the galvanometer (deflecting it to the right), to *B*, to the centre of the left lever, through the *X* back stop to the right front contact screw, along the zinc spring back to the negative pole of the battery.

Depression of the left key joins the positive pole of the battery through the galvanometer to the line *viâ* the copper spring and left lever. The current passes through the distant apparatus to earth and thence back to *A*, right lever and back stop to *Y*, to the left front contact screw, and zinc spring back to the negative pole of the battery.

The path of the received current should be considered in relation to the distant station, which may be either a single needle or a similar instrument. It has been pointed out that the right key connects the positive pole of the battery to the up-line terminal. At a down station this terminal is connected to line, and therefore the path of the current from the down station is from the positive pole of the battery along the line to the up station (represented by Fig. 87). It passes through the galvanometer from left to right (deflection to right), to *B* to the centre of the left lever through the *X* back stop to *U* and *U*-circle of the relay, through the two coils in parallel to *D* and *D*-circle (direction *U* to *D* causing *T* to go over to *M*), to *Y*, through the *Y* back stop, along the right lever, to *A*, to earth, and thence back to negative pole of the down-station's battery. The relay tongue completes the circuit of the local battery through the right sounder, thus producing the "dash" signal required. If now the down station depresses the left key the direction of the current is reversed, thus deflecting both galvanometers to the left and actuating the up relay in the reverse direction. This causes *T* and *S* to be connected and the "dot" sounder actuated.

Up and Down Offices.

The fact that the apparatus connections between the up and down line terminals of the set are identical at up, down, or intermediate offices is of vital importance. It should be borne in mind that the difference in connections at these offices lies solely in the joining of the up and down line terminals to line and earths, or to up line and down line as the case may be. At an up station the up line terminal is joined to earth and the down line terminal to the line to the down station. At a down station the down terminal is earthed and the up line terminal connected to line. At an intermediate office the up line terminal is joined to the up line and the down line terminal to the down line. This applies to single needles, double-plate sounders, sounders—simplex and duplex—and Wheatstone sets. The apparatus connections are the same at every class of office, but the up and down line terminals are joined up in accordance with the above rules.

Prevention of Sparking at Relay Contacts.

The sounders are each wound to a resistance of 20$^{\omega}$ and each is shunted by a 500$^{\omega}$ resistance coil to prevent sparking at the relay contacts. The electromagnets have a considerable self-inductance, the effect of which is to oppose the rise of the current upon the making of the circuit. Upon breaking the circuit the lines of force created by the current cut through the windings and generate an E.M.F. in the same direction as that due to the battery. At the moment when the circuit is broken this E.M.F. adds to that of the battery, and the result is a spark. The shunt across the sounder provides a path for the current due to the E.M.F. of self-induction, other than that through the battery and slightly broken contact. The result is that the E.M.F. between the tongue and the contact point is reduced to a minimum, and sparking with its resultant wearing and roughening of the contacts is avoided.

Earlier Form of Commutator.

The form of commutator shown in Fig. 87 does not

short-circuit the battery if both keys are simultaneously depressed. In an earlier form this was so, the difference in the connections being that the right front contact screw was directly connected to *B* and the left front similarly connected to *A* instead of *viâ* the respective backstops. This point is, however, dealt with in Chapter XVI (page 487).

Arrangement of Apparatus.

In all new double-plate sounders the galvanometer is

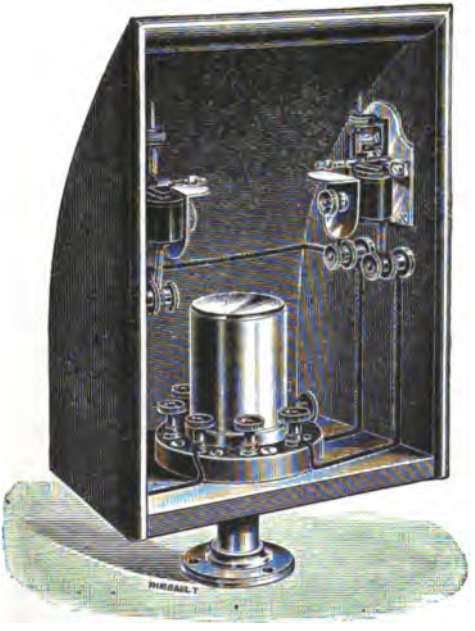

Fig. 88.—Double-plate sounder with the relay in the screen.

fixed in the screen and the relay upon the table, instead of *vice versa*. The advantage gained is that the relay is more accessible for adjustment, and that the sounders and galvanometer can be simultaneously observed.

Adjustment.

The adjustment of the plate sounders is similar to that

of the ordinary sounder previously described. The tension and upward play of the armature are limited by the respective screws. The bobs which strike the sounding plates are screwed upon the armature lever, and their position along the lever may be varied. The lever is inclined upwards, and consequently the position of the bob determines the proximity of the cores and armatures when depressed.

The condition of a battery varies, and its E.M.F. and internal resistance may have any value between the limits given on page 40. It will therefore be seen that the current through the sounders varies, which is the principal reason for the provision of adjustments. Very weak local batteries will require the tension to be very small and the play of the armature as limited as possible. The volume of the signals may then be increased by moving the ball to the outer end of the armature rod.

The adjustments of the relay are—(i) For neutrality. (ii) For play of tongue. (iii) For centring of the tongue. (iv) Tension on the springs.

When a relay is first sent out it is in a neutral condition when the spacing screw stands in the central position between the extreme limits of maximum spacing and maximum marking. If the relay is entirely out of adjustment the following procedure is recommended—

(i) Remove the springs and then place the spacing screw in its central position, *i. e.* with an equal number of threads visible upon each side of the block.

(ii) Clean the contacts and adjust them until the relay is neutral and the required amount of play has been given. Then clamp the contact screws in position.

(iii) Put on the springs and adjust until the tongue is exactly midway with the least possible amount of tension.

The object of the first operation is to ensure that the contact carriage is in the central position, thus allowing the spacing screw to be turned to an equal extent in either direction, should necessity arise. It is only by repeated improper alterations of the contact screws themselves that, with the relay in neutral condition, the carriage could be placed so far out of the central position that the spacing screw could only be turned in one direction.

It is recommended that in all cases of defective regulation the springs should be removed and the relay set

neutral. The adjustment by passage of working signals is not so satisfactory, and frequently entails re-regulation after a comparatively short time. The play of the tongue should be as small as possible, but it is not wise to make the adjustment too fine. On the other hand, too much play seriously "clips" the signals.

If one of the spiral springs becomes loose, the distant sending produces a series of reversals. Defects in the local circuit reveal themselves during the adjustment for neutrality. Unless the defect in the regulation is quite obvious it is far better to entirely re-adjust the relay.

Faults.

Defective contacts between the levers and the *X* and *Y* back stops may be caused by dirt or by insufficient tension upon the key springs. Upon a circuit with double-plate sounders at either end this would cause a current to be sent out only by the key whose back contact was defective. It would also entirely prevent reception. If reception was not interrupted whilst one key only sent out a current, either the other key front or top back contacts are defective or one pole of the battery is to earth.

It may be well to draw attention to the fact that if both keys send out their current in the usual way, both *X* and *Y* back contacts have been proved to be perfect. Any signal perfectly sent or received proves every portion of the apparatus through which the current has had to pass, and, therefore, these parts do not need to be examined. This is of course quite an obvious fact, but its importance cannot be too greatly insisted upon.

Ability to send but not to receive, or, in other words, inability to stop a call, is due to either a fault in the home sending circuit or in the distant receiving circuit. If the depression of the home key cuts off the received signals and holds the galvanometer needle vertical the fault is in the home sending circuit, and as neither key sends out a current, but on the contrary disconnects the circuit, the fault is probably due to the disconnection of the battery. If the depression of a key did not prevent the reception of signals the battery leads are short, circuited or both poles of the battery are to earth. If the depression of a key

stopped the reception of signals, but the galvanometer showed currents due to the home-battery and the distant battery joining together, the fault lies in the distant receiving circuit, *i. e.* from *X* through the relay to *Y*.

A defect in the local circuit is at once revealed by the fact that signals are received upon the galvanometer without the plate sounders being actuated. Line faults are usually even more obvious, but their effects will be considered later.

Current required.

The sounders have a figure of merit of 73 m.a., and are worked by a 2-cell large Daniell battery. The line battery consists of a sufficient number of No. 3 Leclanché cells to provide a current of from 14 to 17 m.a. with the relay in series.

In Chapter II it was shown that the best method of joining up the coils of an electromagnet was that which gave a resistance most closely approximating to the resistance of the rest of the circuit. With the "B" relay the coils should be placed in series when the total resistance of the circuit exceeds 150Ω (of which 50Ω is for the relay) and in parallel when less. With the "*A*" form of relay the coils should be in parallel only when the total resistance of the circuit is under 300Ω (of which 100Ω represents the relay). These rules also show whether it is more economical to provide 28 m.a. with a 50Ω or 100Ω relay resistance, or 14 m.a. with a 200Ω or 400Ω relay resistance.

THE SINGLE CURRENT SOUNDER.

The object gained by employing the single current sounder, as opposed to the direct sounder, system lies in the economy of battery power which, under certain conditions defined later, results from the use of the relay-worked instrument.

The volume of the signals is independent of the value of the current received, and the relay permits a wider percentage variation in the current received before working is rendered impossible. Moreover, the use of the relay gives greater elasticity of adjustment.

Connections.

The connections of the apparatus are shown in Fig. 89. The centre of the key goes to the left side of the single current galvanometer, the right terminal of which forms the down line terminal of the set. The positive pole of the battery is connected to the front stop of the key, and the relay is joined up in place of the sounder of a direct set. The down side of the relay goes to the back stop, and the

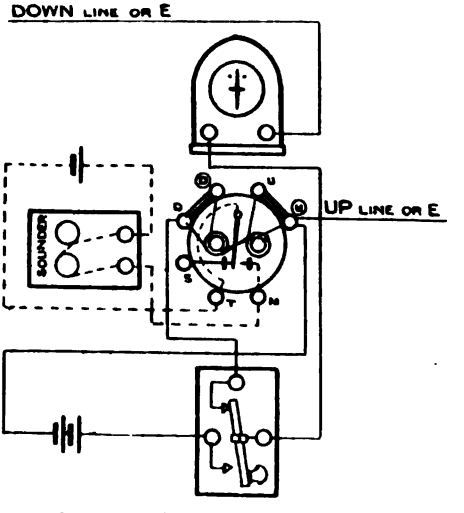

Fig. 89.—Single-current sounder connections.

up side forms the up line terminal to which the negative pole of the battery is also connected. If it is borne in mind that *U*-circle is the up line terminal the connections of the set are readily remembered. The sounder and local battery are joined up between *T* and *M*.

The relay is given a distinct spacing bias, which should be sufficient to smartly return the tongue to *S* upon the cessation of the current, but which should not be so great as to cause clipping of the signals.

The set is joined up to line and earth in the manner

previously described.* If the up station depresses the key a current flows from the positive pole of the battery through the galvanometer along the line to the down station through the down relay (direction *U* to *D*, causing *T* and *M* to be joined), through the back stop of the key, through the galvanometer to earth and thence back to negative pole of the up battery. The current through the down relay causes the tongue to move over to *M*, thus completing the circuit of the local battery through the sounder. When the key is released the spacing bias re-asserts itself and returns the tongue to the spacing side, so ending the mark.

Faults.

The locating of faults is an extremely simple matter, but it should be noted that the set may be divided into main, sending, receiving, and local circuits. The main circuit is that common to both sending and receiving, viz. from the centre of the key through the galvanometer to line or earth, as the case may be, and also *U*-circle of the relay to line or earth. The sending circuit is from *U*-circle, through the battery and front contact point. The receiving circuit is through the back stop and relay to *U*-circle. The local circuit comprises the sounder, local battery and *T M* contacts.

One example of the deduction of the position of a fault will be given in order to illustrate the method still further. Let the symptoms be that the call cannot be stopped. The reception of signals proves the main circuit at both ends, the receiving circuit at the receiving end, and the sending circuit at the sending end. This leaves the sending circuit and distant receiving circuit. If depression of the key cuts the circuit the fault is in the sending circuit. If not, the fault is in the distant receiving circuit, *i. e.* in the circuit through the back stop of the key and the relay. If it is noticed that, upon holding down the key, a current is sent out when the distant station obviously has his key at rest, the fault is either short circuit of the relay or possibly the local battery circuit is defective, and the movement of the galvanometer needle has not been noticed.

* If the reader has the least doubt upon this point he should refer back to page 172 and not proceed further until he has thoroughly grasped the principle.

It frequently happens that two defects of apparently opposite character are produced by defective regulation. Sticky dashes and missed dots may be caused by insufficient bias upon the relay and too much tension upon the spring of the sounder. It may also be caused by the armature of the sounder being allowed to approach the cores too closely, with the result that the marks stick. Instead of this being put right the spacing bias is increased and sticky dashes still occur whilst the dots are missed.

Adjustment.

The armature of the sounder is sometimes allowed to approach very near to the cores in order to get loud signals from a weak local battery. A definite clearance should, however, always be maintained and the remedy should always be applied at the point where the defect exists.

Coils in Parallel or Series.

If the coils of the relay are placed in series a current of 15 to 20 m.a. is required, whilst in parallel 30 to 40 m.a. must be provided. The arrangement which requires the least battery is chosen. Precisely the same factor determines whether direct or relay worked sounder is to be employed.

The resistance of the *B* relay is so small that its coils should always be placed in series. With an *A* relay the coils should only be in parallel when the resistance of the line itself is under 170Ω.

Direct *v.* Single Current Sounder.

With 13 cells a direct sounder may be worked over 58Ω line resistance, whilst the same power employed for working a single current sounder would work through a line having a resistance of 140Ω with the *A*, and 340Ω with the *B*, type of relay.

Form of Battery.

The local battery was formerly a 5-cell Large Daniell, but the standard practice is now to use either a 3-cell Large Daniell or a 2-cell Bichromate. The latter is,

however, only used where Bichromate cells are already installed.

Local Inker.

A local inker is sometimes used instead of a sounder, and occasionally it is joined in parallel with a sounder. The instrument (Fig. 65) is similar to the direct inker, but is minus key and galvanometer, and is wound to a resistance of 40ω. A 500ω resistance coil fixed inside the instrument is connected across the terminals of the electromagnet to prevent sparking at the relay contacts. Its joint resistance is 37ω and its figure of merit 69 m.a. The speed of the slip should not be less than 6 feet nor more than 7 feet per minute.

Use of "D" Relays.

For reasons of economy single current sounder circuits are now worked with "D" relays, of the form illustrated in Fig. 81. The relay is, however, mounted upon a wooden base carrying the terminal screws, and is furnished with a brass cover having a glass top. It is singly wound to a resistance of 200ω, requires a current of 25 m.a., and costs about one-third as much as a P.O. standard polarized relay.

CHAPTER VI

CAPACITY, CONDENSERS, AND THE DOUBLE-CURRENT SOUNDER.

CONDENSERS.

A CONDENSER essentially consists of two conductors separated by an insulator termed, in this connection, the dielectric. The capacity of the condenser is the value of its charge or the quantity of electricity with which it is charged by unit potential difference (p. 14). A condenser having a capacity of one farad would therefore be charged with one coulomb of electricity if a difference of potential of one volt existed between its terminals.

CAPACITY.

In order to appreciate the effects and behaviour of capacity generally, it is necessary to carefully consider the fundamental difference which exists between a conductor and an insulator. The former permits the passage of a continuous electric current through it, whilst the latter does not. Now the creation of a difference of potential between the two sides of an insulator (*e.g.* a slab of paraffin wax) produces an electric strain through it. In the case of the lightning protector it is clearly demonstrated (Chapter XVIII) that a large potential difference produces so great a strain upon the layer of air between the plates that the air breaks down, and a disruptive discharge occurs. Again, it is well known that a leyden jar may be broken into fragments by applying a sufficiently large difference of potential. The creation of a difference of potential between the sides of the slab of wax produces a strain and a current flows into the dielectric at one side, and a current of

equal value flows out at the other. This current ceases when the backward pressure of the dielectric is equal to the forward pressure of the battery, in other words when the backward E.M.F. of the condenser is the same as that of the battery. If the battery is removed and the terminals of the condenser are connected by a conducting path, the strain will relieve itself by discharging the quantity of electricity whose admission gave rise to the state of strain. This discharge is a current from the positive to the negative electrode of the condenser through the conducting path substituted for the battery.

Electro-static Lines of Force.

The lines along which electric strains occur are termed electric lines of force, and a definite numerical value is assigned in a similar manner to that given to magnetic lines of force. A static line of force begins upon a conductor of higher potential and ends upon one of lower potential. In the case of a charged condenser they extend from plate to plate, and serve to mark out the direction of the electric strain and by their number express its value. There is a tension along their length and they always endeavour to shorten themselves by an attracting pull between the two conductors to which they are attached. Parallel lines of force of similar direction exert a lateral repulsion upon each other.

Electro-static Explanation of Capacity.

Although the foregoing statement represents the simplest and easiest way of regarding the phenomenon of capacity, it may perhaps be well to give also the more conventional or electro-static explanation. Two insulated conductors may be thrown into opposite electrical conditions by means of a battery, influence machine, or other source of E.M.F. The conductor connected to the positive pole of the battery assumes a positive, and that connected to the negative pole assumes a negative potential, and when oppositely charged conductors are joined by a wire a current flows from the conductor of higher "electrical level" or "*potential*" to the lower, thus causing the bodies to regain their normal uncharged condition. The quantity of electricity which

the bodies will contain depends upon the proximity, size, electrical pressure applied, and, lastly, upon the materials insulating them.

Dimensions of Condensers.

Upon connecting a battery to a condenser a current flows until the difference of potential across the condenser is the same as the E.M.F. of the battery. If the battery is short circuited the condenser discharges in the opposite direction to that of the current which charged it.

The capacity of a condenser depends upon its dimensions and the material of which the dielectric is composed. With a given thickness of dielectric between two metal plates of equal size the capacity is directly proportional to the area of either plate. The reason is that in doubling the area of the plates the area of dielectric strained is doubled, and therefore, since the difference of potential is the same between every part of the one plate and every part of the other plate, the quantity of electricity stored is doubled.

By doubling the thickness of the dielectric the capacity is halved if the size of the plates is unaltered. This is due to the greater stiffness of the thicker dielectric to an electric strain.

Specific Inductive Capacity.

If a number of condensers are constructed of precisely equal dimensions, but with different materials as dielectric, it will be found that their capacities will also differ to a considerable extent, the condenser in which the plates are separated by air having the smallest capacity. The values of the capacity obtained with the various materials substituted for the air dielectric are therefore stated relatively to the capacity of the air condenser, which is taken as unity. Since the *relative* capacities are always the same for the various materials, provided the condensers are of equal dimensions, the numerical values refer solely to the dielectric material. The numbers are those by which the capacity of an air condenser must be multiplied in order to obtain the capacity of the condenser when the material in question is substituted for air. The number assigned to each substance is termed its specific inductive capacity, or briefly its specific capacity.

The values of the specific capacity of a few materials commonly employed are given below:—

Material.	Specific capacity.
Air	1
Paraffin wax, clear . .	1·92 to 1·977
,, ,, milky .	2·47
Paraffined paper . .	2·8
India-rubber, pure . .	2·34
,, ,, vulcanized .	2·94
Ebonite	2·56 to 3·15
Gutta-percha . . .	4·2
Mica	5
Flint glass . . .	6·57 to 10·1

The capacity of two copper wires of equal diameter and length covered with an equal thickness of gutta-percha and vulcanized india-rubber respectively will, if submerged, have relative capacities in the ratio of 4·2 to 2·94.

The capacity of a plate condenser varies directly as the area and specific capacity and inversely as the thickness of dielectric strained. Three metal plates separated by two dielectric slabs will give twice as great a capacity from the centre to the two outer plates as two sheets of metal separated by a single dielectric slab. The three-electrode condenser is clearly equivalent to two two-plate condensers joined together, thus doubling the area of dielectric strained, but with the same potential difference applied throughout. The capacity in microfarads of a condenser with two equal plates separated by a single sheet of dielectric is approximately:—

$$\frac{a}{t} \times k \times \cdot 000,000,2246$$

where a is the area of dielectric strained, *i. e.* the area of either metal plate, k is the specific capacity of the dielectric, and t its thickness in inches.*

* The formula is obtained as follows:—

$$K \text{ (absolute electro-static units)} = \frac{a\,k}{4\,\pi\,t}$$

1 absolute electro-magnetic unit of capacity = v^2 static units where v

Condensers in Parallel and Series.

Condensers may be joined up in two different ways, viz. in parallel and in series, or cascade as it is sometimes termed. The latter method is very seldom if ever used in telegraphy, but it has a definite sphere of utility which will be apparent when the question of joint capacity has been considered. The two methods are illustrated in Figs. 90 and 91.

When condensers are joined up in parallel it will be quite evident that the effect is to increase the area of dielectric subjected to strain, and therefore that the resultant

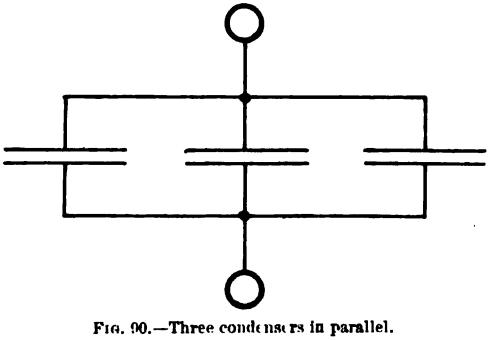

Fig. 90.—Three condensers in parallel.

or joint capacity of the combination is obtained by adding their capacities together. In the case illustrated, in Fig. 90, if the respective capacities are 5 m.f., 2 m.f., and 1 m.f., the joint capacity is $5 + 2 + 1 = 8$ m.f.

Three condensers are depicted in Fig. 91 joined in series or cascade, and the joint capacity is then less than that of

---

is numerically equal to the velocity of light, viz. 3×10^{10} c.m. per second.

10^{15} m.f.s = 1 absolute electro-magnetic unit of capacity.

$$\therefore K \text{ in m.f.s} = \frac{a\,k \times 10^{15}}{t \times 4 \times 3{\cdot}1416 \times 3^2 \times 10^{20}}$$

$$= \frac{88.42\,a\,k}{t \times 10^9} \text{ where } a \text{ and } t \text{ are in cms.}$$

$$= \frac{88{\cdot}42 \times 2{\cdot}54^2 \times a\,k}{t \times 2{\cdot}54 \times 10^9} \text{ where } a \text{ and } t \text{ are in inches.}$$

the smallest condenser. This is due to the greater thickness of dielectric interposed between the two extreme outside plates, since each condenser placed in series interposes the thickness of its dielectric in the direction of the electric strain.

The joint capacity of condensers in series is ascertained in the same manner as that of circuits placed in parallel. It is equal to the reciprocal of the sum of the reciprocals of the separate capacities. Taking the same values as before, viz. 5 m.f., 2 m.f., and 1 m.f., respectively:—

$$\text{Joint capacity} = \frac{1}{\frac{1}{5} + \frac{1}{2} + \frac{1}{1}} = \frac{10}{17} \text{ m.f.}$$

In the case of two condensers placed in *series* the above rule may be simplified in the same way as that for two

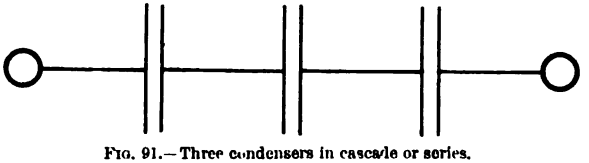

FIG. 91.—Three condensers in cascade or series.

circuits in *parallel*, viz.: that the joint capacity of two condensers in series is equal to their product divided by their sum. Similarly, if condensers of equal capacity are connected in series the joint capacity is equal to the capacity of one of them divided by their number.

Example.—(*a*) What will be the joint capacity obtained by connecting a condenser of 5 m.f. in series with one of 3 m.f. capacity? (*b*) Find the joint capacity of five 2 m.f. condensers joined in series.

$$(a)\ \frac{5 \times 3}{5 + 3} = 1\tfrac{7}{8} = 1{\cdot}875 \text{ m.f.}$$

$$(b)\ \frac{2}{5} = {\cdot}4 \text{ m.f.}$$

DIELECTRIC FOR CONDENSERS.

The choice of materials for use as dielectric in telegraph condensers is extremely limited. Glass is too fragile for

use in extremely thin sheets, and by sufficiently increasing the thickness the size and cost of the condenser are enormously enhanced. Gutta-percha can be made in very thin sheets, but unless kept under water it rapidly becomes hard and brittle. Mica would certainly be an ideal substance, were it not for the fact that its cost prevents its use in any but standard condensers. For telegraph purposes paraffined paper is exclusively employed with entirely satisfactory results.

Condensers used in Telegraphy.

Formerly, telegraph condensers were built up of alternate sheets of paraffined paper and tinfoil, two sheets of paper being used to separate the adjacent sheets of tinfoil. The two top corners of every paper were cut off, but only one corner of each foil was removed. As the foils were laid alternately with their whole corners in opposite directions, it will be obvious that the corners of foils 1, 3, 5, 7, etc., projected beyond the papers upon the one side, whilst foils 2, 4, 6, 8, etc., upon the other, thus affording a simple and obvious method of connection. The whole series was held in position by two iron plates of rather larger size than the paper, and securely bolted together at the corners.

The method of condenser manufacture now in use by the Post Office is based upon the process introduced and patented by G. F. Mansbridge in 1900, by means of which the cost of building condenser plates has been very materially decreased. This process consists in the use of the material known as "tinfoil paper," in place of the metallic foil and plain paper previously employed. The tinfoil paper for making condensers is prepared in the form of continuous reels, and the process of making a condenser plate consists simply in winding up into the form of a flat roll two strips of this paper, each strip being perhaps 30 feet long, the precise length depending, of course, upon the capacity of the plate required. The tinfoil paper, which is somewhat similar to the paper used commercially for wrapping up packages of tea, etc., is prepared by pasting tin which has been reduced by chemical processes to a state of extremely fine sub-division, upon one side of a thin "body paper." To render this coating of tin paste practically continuous,

and to improve its electrical conductance, the prepared paper is subjected in the course of manufacture to a calendering process, which consolidates and burnishes the minute particles of tin, and firmly fixes the metal to the body paper. It will be obvious that when two spirals of such paper are rolled up together the thin film of tin on one spiral will be separated from that of the other spiral by means of the paper which forms the dielectric. To obtain very high insulation, and to increase the dielectric strength it is usual to interleave between the strips of tinfoil paper a strip of thin plain paper, *i. e.* two strips of tinfoil paper, and two strips of plain paper are arranged alternately and rolled up together. The coating of tin on the tinfoil paper is so extremely fine that it would not be possible to make a soldered electrical connection to it, consequently the "lugs" by which contact is maintained consist of strips of thin metal foil laid between the foiled surfaces and the interleaving paper, separate lugs being of course used for the two foiled surfaces. After being removed from the winding machine the rolled strips are thoroughly desiccated by prolonged heating at a temperature of about 200° F., and the last traces of moisture are then extracted by means of desiccation under vacuum. When thoroughly dry and still in vacuo, hot paraffin wax is allowed to flow into the vacuum pan, and after the plates have soaked for some hours so that the wax may thoroughly penetrate the pores of the paper, the vacuum is broken, the wax is drained off, and the plates are then taken out and put under considerable pressure until cold. They are then tested for capacity and insulation. Obviously the value of the capacity can be adjusted by peeling off some of the outside layers to reduce the capacity, or by re-soaking the plate and subjecting it to a greater pressure to increase the capacity. The standard plate is of the 2 microfarad size, and this contains 21 square feet of surface to each electrode. The dimensions of a finished 2 m.f. plate are $7\frac{1}{2}'' \times 4\frac{1}{2}'' \times \frac{1}{2}''$ thick, and its average weight is 13 ozs. The specific inductive capacity of the paraffined paper may be taken at 2·8. Calculations made from a condenser constructed of "tinfoil paper" would give results somewhat higher than this figure, due to the fact that the effective thickness of the body paper is less than its apparent thickness owing to the particles of tin being so thoroughly

driven into the pores of the paper in the process of manufacture. The insulation resistance obtained from a condenser depends upon many details of manufacture, and also upon the conditions under which the test is made, particularly as regards temperature. It is useless to look for high insulation unless the last traces of moisture have been removed from the paper, and unless the paraffin wax and the paper are of the highest quality.

It should be added that the whole arrangement is firmly

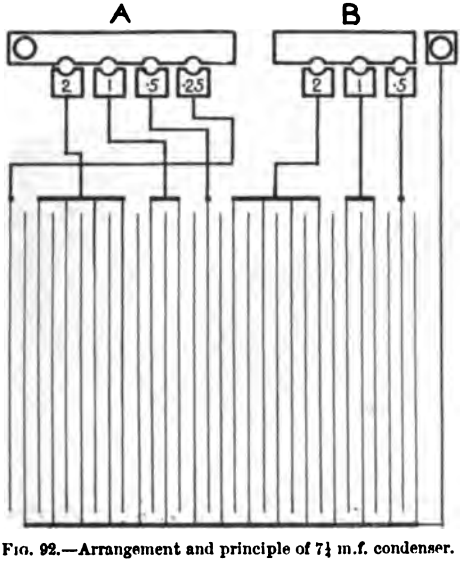

FIG. 92.—Arrangement and principle of 7¼ m.f. condenser.

clamped between iron plates in precisely the manner described in the case of the older type of condenser.

The external appearance of the $7\frac{1}{4}$ m.f. condenser and its connections are shown in Figs. 92 and 93. It is divided into two sections in order that it may be used in place of the two separate condensers which would otherwise be required upon long duplex and other circuits. The seven section lugs are connected to condenser plates of the capacities indicated in Fig. 92. Capacity is inserted by

plugging the main and section bars together. To obtain the full capacity 7¼ m.f. *A* and *B* are joined together and all the plugs inserted so as to connect all the plates of the condenser together.

Insulation of Condensers.

Immediately the insulation of a condenser fails it becomes a mere resistance and incapable of holding a charge.

For use upon cable circuits condensers of far larger capacity and divided into three sections are frequently

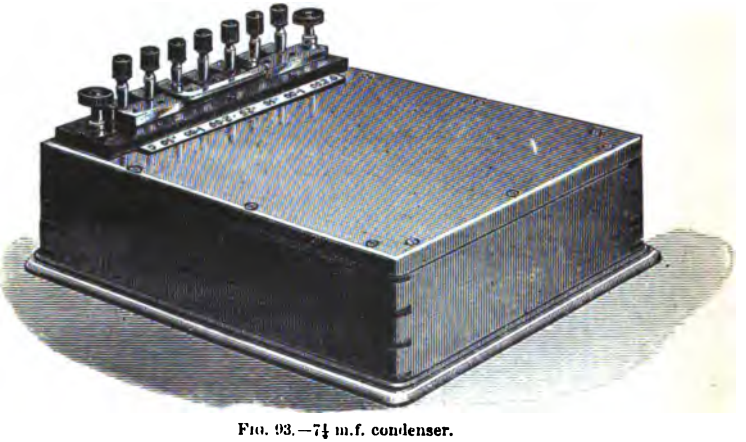

Fig. 93.—7¼ m.f. condenser.

employed. This point is however dealt with in connection with duplex circuits.

Specification of Insulation and Capacity.

The temperature coefficient of the insulating materials being very high, a standard temperature must necessarily be decided upon, and this, in the case of condensers, is usually 60° F. At this temperature, and with a pressure of 400 volts, the minimum insulation of a new condenser according to the Post Office specification is 1000 megohms per microfarad, the insulation being measured after one minute's "electrification," *i. e.* the reading upon which the insulation is to be calculated is observed at precisely one minute after

the battery is first applied to the condenser (see page 651). It is necessary to be precise upon this point as the electrification of a good paraffined paper condenser is very considerable. As compared with that during the first minute there is, however, very little subsequent electrification.

The insulation of a $7\frac{1}{4}$ m.f. condenser after one minute's electrification would, at 60° F., have to be at least 138 megohms.

The capacity of telegraph condensers is correct to 5% above or below their nominal values.

Condenser Discharge.

The discharge of a condenser when employed in ordinary telegraphy is always accomplished by a flow of current from the positive to the negative side of the condenser through the circuit connecting them. If, however, the resistance and self-inductance of the discharging circuit are extremely low and bear a certain relation* to the capacity of the condenser, the discharge becomes oscillatory. This phenomenon plays a vitally important part in wireless telegraphy, and it may best be explained by analogy. Take a flat piece of whalebone 3 or 4 inches in length and clamp one end in a suitable hand-vice. If the whalebone is deflected and suddenly released it will vibrate backwards and forwards past its normal position of rest, but the amplitude of its vibration will grow gradually less and less until finally all vibration ceases. This experiment is supposed to have been made in air, and it is the friction between the moving whalebone and the air which finally brought it to rest. Let the same experiment be repeated, but with the whole arrangement immersed in treacle. When the spring is pulled aside and released it will slowly return to its normal position without oscillation, because the frictional resistance is too great. In this analogy the spring corresponds to the charge of the condenser, and the medium in which it dissipated its energy to the external circuit through which the condenser is discharged. If the resistance and inductance of the

* The discharge is oscillatory if the ohmic resistance of the discharging circuit is less than the square root of four times the inductance in henries divided by the capacity of the condenser in farads.

circuit is small, the charge swings backwards and forwards, first from the positive to the negative side, and in overshooting its mark makes the formerly negative side positive, and the formerly positive side negative. This results in a discharge in the reverse direction, which again overshoots the mark, and makes the formerly positive side again positive. This oscillatory current continuously diminishes in magnitude until, finally, it dies away altogether.

THE DOUBLE CURRENT SYSTEM.

In the single current system the tongue of the relay is restored to the normal position upon cessation of the current either by a magnetic bias, or by a spring in the cases where non-polarized relays are employed. In the double current system a polarized relay is necessarily always employed, and a current in the reverse direction to the marking current is employed to restore the tongue to the spacing side. This current is termed the "spacing" in contradistinction to the "marking" current, *i.e.* the current which causes the completion of the local circuit. The difference between a series of signals sent under the two systems is that in the double current arrangement the blank spaces between the "marking" currents of the single current system are filled by a reverse or spacing current. At rest the key sends out a spacing, and when depressed a marking current, which latter is in the same direction as that in the single current system.

Advantages of Double Current System.

The use of the double current system upon long lines increases the speed of working, and gives greater permanence of adjustment as compared with single current working. The causes of these advantages may be summarized as follows:—

1. It hastens the discharge of the line which is ordinarily comparatively slow.
2. The relay is worked in the neutral, and therefore in its most sensitive and rapid condition.
3. It eliminates the effects of residual magnetism in the cores of the receiving relay.

4. The effects of a variation of received current are reduced since both marking and spacing currents are equally affected, and the instrument is therefore self-adjusting.

Reverse Current and Charge upon the Line.

In order to clearly realize the effect of the spacing current it is necessary to consider the effect of the capacity of the line upon the working of a circuit.

A condenser has been defined as two conductors separated by an insulating medium, and it will therefore be seen that any telegraph line may be regarded as a condenser. The aërial line wire itself forms one conductor, and the earth below it the other. These two conductors are separated by air, and there are, therefore, all the essential features of a condenser. In the case of a subterranean or submarine cable the wire and the earth are much closer together, and the gutta-percha insulation which separates them has a much higher specific capacity than air. The result is that the capacity of an underground circuit is far higher than that of an open line. In fact, one mile of gutta-percha underground has approximately the same capacity as twenty miles of open line. With the increased use of air-space cable this disadvantage has, however, been materially reduced.

When an earthed battery is connected to a telegraph circuit the capacity of the line has to be satisfied before the full value of the current is received at the distant end. The charging of the line as a condenser occupies a definite length of time which is much greater for very long or underground circuits than for short open lines. Upon stopping the current the line discharges the quantity of electricity upon it. This discharge current flows from the line at both ends if both are earthed, and at the receiving end it tends to prolong the mark. This discharge is also comparatively slow, and therefore on very long circuits the interval between successive signals must be made greater in order to prevent their running together. Very sharp dots would be lost entirely, due to the quantity of electricity sent on to the line being small and insufficient to fully charge it. The small quantity of electricity would distribute itself over the line and a very small discharge

current would probably flow out at both ends. That at the receiving end would be quite insufficient to actuate the apparatus.

When the double current system is employed the reverse current hastens the discharge of the line which occurs almost entirely through the sending battery. In the case described above the reverse current would produce a sort of whip-like flick of current. To cause a whip to crack it is moved forward and suddenly jerked back. This apparently irrelevant illustration is, as a matter of fact, rather a close analogy to the actual effect of the reverse current in producing sharper and therefore more rapid signals.

Detailed Explanation involving Knowledge of Chapter VII.

The precise behaviour of the reverse current may readily be deduced from a consideration of the principles explained upon page 249 *et seq.* The charge upon a line due to a marking current from an up station is represented by a triangle similar to that shown in Fig. 111, but drawn above the line as in Fig. 146. If, now, the sending end is suddenly earthed, as by releasing a single current key, the line discharges, two-thirds of the charge flowing to earth at the sending and one-third at the receiving end. This one-third is in the same direction as the marking current, and therefore prolongs the signal. Had the battery at the sending end been reversed instead of earthing the line it will be seen that practically the whole of the discharge of the line would pass through the reversed battery. This would clearly prevent the prolongation of the signal.

Consider now the case where the line is negatively charged by the spacing current as shown in Fig. 111. Instantly the battery is reversed a heavy current flows from it, reversing the sign of the charge upon the line and reproducing the conditions described above. But during this process, rapid as it is, a certain portion of the previous negative charge is dissipated by a negative discharge to earth at the receiving end. This expedites the process of clearing the negative charge before the reverse charge is commenced. The discharge at the receiving end is in the spacing direction, and therefore the actual marks are unaffected.

Other Advantages of the Double Current System.

The reverse current reverses the magnetization of the relay and therefore the effects of residual magnetism are minimized (see page 166).

The advantage stated under the heading 3 on page 222 also carries with it the corollary that less battery power should be required to work double instead of single current, because there is in the former case no magnetic bias to be overcome. In practice, however, a small spacing bias is always given to the relay in order to prevent the sounder from chattering. For, if the relay is set exactly neutral, it is so sensitive that the extremely minute currents induced by neighbouring working circuits or by slight earth or stray currents will cause the tongue to vibrate. Upon the other hand, if the tongue continuously remains at *M* when the circuit is idle the local battery is needlessly used.

The last advantage, stated under heading 4, is one of considerable practical importance. Since the marking and spacing currents will be equally and similarly affected by a variation in the received current, the instrument is consequently self-adjusting. In the case of a single current set, the relay is given a definite and constant bias and variations in the value of the current received therefore produce irregularity in the received signals. Again, where a number of stations are placed upon one circuit the current sent out by each office varies and, with the single current system, working becomes practically impossible on account of the re-regulation of the relay which is required for each station. Part of this trouble is of course due to residual magnetism. With double current working there is practically no bias upon the relay, and re-regulation is obviated since an office from which a weak marking current is received also furnishes an equally weak spacing current. The office sending a strong marking current also sends an equally strong spacing current, and the working of the relay is therefore not affected by the difference. With the single current system a large current would leave a considerable amount of residual magnetism.

Double Current Key.

The double current key (Fig. 94) is provided with a

switch, which joins up the relay for reception in one position, and in the other connects the battery between the up and down terminals in a direction which depends upon the position of the key. It will be obvious, that, since the key when at rest sends out a spacing current, a means of disconnecting the battery and joining up the receiving apparatus must be provided. This is, then, the function of the "send" and "receive" switch fixed upon the left side of the key-handle.

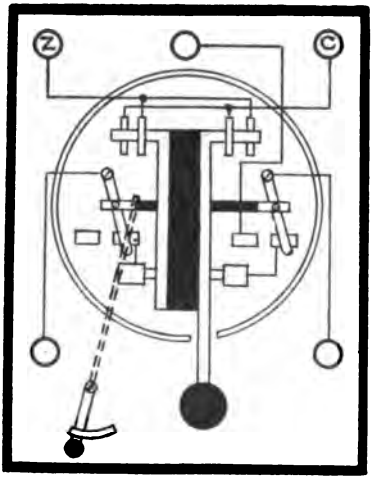

FIG. 94.—Plan of a double current key.

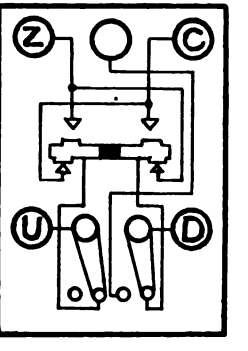

FIG. 95.—Conventional method of illustrating a double current key.

The key is furnished with five terminals, two of which, *Z* and *C*, are used for the battery, two for the up and down sides of the key, and one, the centre terminal, for the receiving circuit. The key itself consists of a divided lever furnished with four contact points which play between four platinum-tipped springs connected to *Z* and *C*. A section of the end of the key with the lever in its lower position is shown in Fig. 95. Terminal *C* is thus connected through the lower "copper" spring and left-hand side of the lever through the right-hand side of the left switch lever to *U*. *Z* is connected *viâ* the lower "zinc"

spring and right side of the lever through the right contact of the right switch to *D*. Upon depression of the key the end rises and the left side of the lever breaks contact with the lower "copper" spring and makes with the upper "zinc" spring. The right side of the lever, simultaneously,

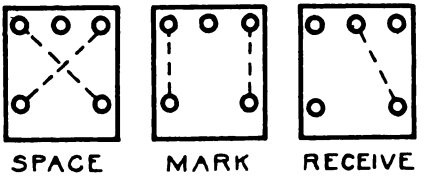

FIG. 96.—Skeleton connections in each position of the key.

breaks with the "zinc" and makes with the "copper" spring, the result being that *Z* and *C* are respectively connected to *U* and *D*. Upon the handle of the switch being moved to "receive," the two levers of the switch, which are mechanically (but not electrically) joined together,

FIG. 97.—Double current key.

move over to their left contacts thus disconnecting the key lever altogether, and joining the centre terminal to *D*.

The illustration of the actual appearance of the key (Fig. 97) will readily enable its various parts to be related with the theoretical diagram previously given. The skeleton connections in each position of the key are shown in Fig. 96.

Connections of Double Current Sounder.

The galvanometer employed is of the single current pattern previously described (page 169).

The connections of a double current set are shown in Fig. 98. *Z* and *C* are connected to the battery, the front right-hand terminal of the key is connected to the left of the galvanometer whose right terminal forms the down-line terminal of the set. The left side of the key is con-

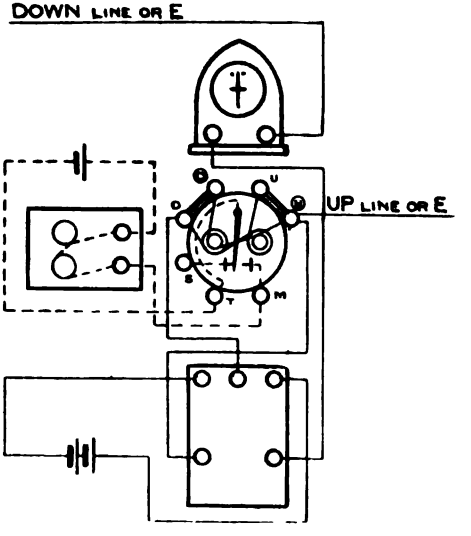

Fig. 98.—Double current sounder connections.

nected to *U*-circle of the relay which forms the up-line terminal of the set. The centre terminal of the key is connected to *D* of the relay. It may be noted that the connections of the single current sounder are similar in several respects to those now under consideration. The front right terminal corresponds to the middle point of the single current key and the centre to the backstop. The up and down line terminals of the set are also the same.

When the key is depressed the direction of the current is the same as in the single current set and, with the

exception of the difference in the keys, its path also is identical.

The connection of the set to line and earth or between up and down lines at a terminal office is the same as that of the other instruments previously considered.

Path of Current.

The path of the current with the switch to "send" but key at rest at the up-station is as follows. From the positive pole of the battery, to *C*, to the left terminal of the key, to *U*-circle, to earth, through the down galvanometer from right to left, to the right side of the key, to the centre of the key, to *D* of relay, through the relay in the direction *D* to *U*, to line, through the up galvanometer from right to left, to the front terminal of the key, to *Z* and thence back to the negative pole of the battery. The tongue of the relay at the down station is therefore held over to *S*. Upon depressing the key the deflections are reversed and the tongue moves over to *M*, thus completing the local circuit and registering a mark at the down station.

The correctness of the apparatus connections may be verified by joining the centre of the key and the wire upon it to the down line terminal and working the key, when the signals sent upon it should be correctly received. It should however be noted that the connection made by the switch from the right side of the key to the centre is not included in the test.

Use of Double Current Set for Single Current Working.

It is occasionally required to temporarily convert a double current into a single current set. This may be done as follows. Take the wire from the front left terminal of the key and join it to the *Z* wire, leaving both terminals free. *Z* and the centre terminal should be connected by a short length of wire and the switch of the key placed at send. *Z* and the centre terminal now correspond to the backstop of the single current key.

Faults.

The position of an apparatus fault may readily be

deduced in the manner already described in the case of the instrument sets previously considered. Faults in the key are comparatively rare since all the permanent connections are made by means of brass straps beneath the base. One of the contacts between the divided lever and the springs occasionally becomes dirty or bent and the result is that the key sends out only one current. Faults in the switch are very rare, but their existence should readily be deduced.

If, after having called for some time, it is noticed (from the galvanometer) that the distant station is endeavouring to stop the call, the fault will lie in the caller's receiving circuit. If, upon applying the test explained above it is found that the relay is unaffected by the caller's key, the fault is in the key switch. It should perhaps be mentioned that the connecting wires occasionally get broken inside their gutta-percha covering with the result that intermittent faults are produced.

Battery Power and Current Required.

Large Daniell cells (instead of Small) are now employed for the line battery, and a sufficient number of cells to furnish a current of from 14 to 17 m.a. being required, and the local battery is now either a 3-cell Large Daniell or a 2-cell Bichromate. It is obvious that a local inker may be substituted for or added to the sounder in the manner previously described.

It should perhaps be added that the only case in which the coils of the relay should be joined in parallel is when there are several stations upon a very short line—the deciding factor being economy of battery power.

CHAPTER VII

THE DIFFERENTIAL DUPLEX.

THE SINGLE CURRENT DUPLEX.
SYSTEMS OF DUPLEX WORKING.

DUPLEX working consists in the simultaneous transmission of two messages in opposite directions over a single wire connecting the two stations. Although there are several methods of doing this, three only are employed in practice. Of these the Bridge method forms the theme of Chapter X, since it is most frequently employed in

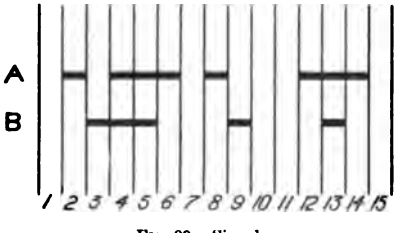

FIG. 99.—Signals.

conjunction with Wheatstone working. The central battery duplex devised for use in conjunction with the Metropolitan telegraph switching scheme is dealt with in Chapter XIII. The third method (differential duplex) is the one most largely employed, and it is worked upon either the single or the double current system. In the former system the working may be arranged in two different ways which may be distinguished as "opposition" and "combination" methods respectively. The latter is employed by the Post Office, but a consideration of the former also is desirable.

In order to clearly realize the underlying principles in

duplex working it will be well to ascertain why the ordinary single current sounder will only permit simplex working. Consider two stations *A* and *B* sending the signals depicted in Fig. 99. These signals and spaces are divided into fifteen parts by the vertical lines so as to show the cases in which two marks are simultaneously sent out. In the first space both keys are at rest, whilst in the second *A* depresses the key and so produces a dot at *B*. As this key rises *B* depresses his key and the result is a mark at *A*. Whilst this mark is proceeding, *A* depresses his key (4) so cutting out his sounder and stopping the mark which he should be receiving. *A*'s sounder also is cut out by the depression of his key and therefore no marks are recorded at either end when both keys are down. When only one key is down at a time the signals are of course transmitted without difficulty, but when both keys happen to be simultaneously depressed (4, 5 and 13) confusion at once results.

In the opposition method of duplex working, when only one key is depressed, the marks are made by the current which is received from the distant station, just as in ordinary simplex working. When, however, both keys are simultaneously depressed, a special condition is established which causes both sounders to register a mark.

Opposition Method.

The general principle of the opposition method consists in splitting the current sent out by the key into two exactly equal parts which respectively pass through the two coils of the sending station's relay. The two currents are of precisely equal strength and pass through the two coils of the relay in opposite directions, so producing no effect upon the sending station's relay. One-half of the current passes to line and through the receiving relay, thus effecting a mark. When both keys are depressed, the two batteries have their similar poles to line. This stops the line current, but leaves the current flowing in the other coil of the relay free to produce a mark. When one key only is depressed the mark is made by the current received from the sending station, but when both keys are down each relay marks with the current from its own battery, due to the stoppage of the line currents.

The skeleton connections of such a circuit, worked with standard relays, are depicted in Fig. 100, but it should be noted that the local circuit has been omitted in order to simplify the diagram. The single current key when at rest earths the split of the relay, and when depressed joins up the earthed battery. One coil of the relay is connected to line and the other to a resistance equal in value to the resistance of the line and the distant apparatus. This resistance is adjusted until the current sent out divides equally between the plain and circle coils of the relay. The arrangements at each end are identical in every particular.

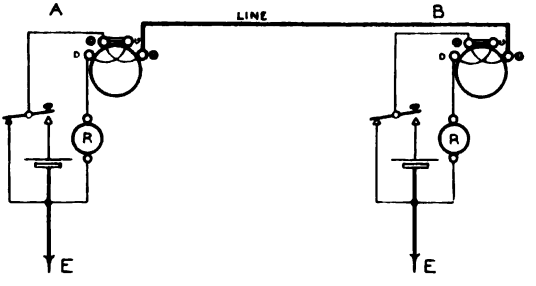

FIG. 100.—Opposition method of duplex working.

OPPOSITION METHOD, PATH OF CURRENT.

The paths of the current may best be considered by tracing the conditions which result when *A* and *B* send the signals shown in Fig. 99.

Condition 1.—Both keys at rest. Tongue held to *S* by magnetic spacing bias given to the relays. No currents flowing.

Condition 2.—*A*'s key depressed. Current flows from the positive pole of *A*'s battery to the split of the relay. Line half of the current passes through the *D*-circle *U*-circle coil of *A*'s relay, along the line, through the line coil of *B*'s relay from *U*-circle to *D*-circle (thus producing a mark), to the centre of *B*'s key, to earth, and thus back to *A*'s battery. The other half of *A*'s current passes through the plain coil of the relay in the direction *U* to *D*, rheostat *R*, and so back to the negative pole of the battery. This circuit is termed

the "compensation" circuit in contradistinction to the "line" circuit. Since the currents in the line and compensation circuits are equal but in opposite directions the relay is not magnetized and no effect is produced at *A*. *B*'s relay however marks by the current received from *A*.

Condition 3.—*B*'s key only is depressed. The current from *B*'s battery divides equally between the line and compensation circuits, and as the two halves pass in opposite directions through the two coils of his relay no effect is produced upon it. *A*'s relay marks with the half of the current which is received from *B*.

Condition 4.—Both keys simultaneously depressed. Both batteries have their negative poles to earth and their positives to line. Since they are of approximately equal E.M.F. no current can flow along the line or line coils of the relays. The only path left open to the current is, at *A*, from the positive pole of the battery, through his own relay from *U* to *D* through the rheostat back to the negative pole of his own battery. Since there is no opposing effect from the circle coil a mark is made at *A* by his own battery. Similarly *B*'s relay marks by the current from his own battery through *U D* coil of his relay. Both relays therefore mark.

Condition 5.—Same as condition 4.

Condition 6.—*B*'s key released, *A*'s still down. When *B* releases his key, *B*'s battery is cut out and *A*'s line current is therefore unopposed. The moment this is re-established *A*'s compensation effect is balanced and his relay spaces thus ending the mark at *A*. At *B* the mark is continued by the current received from *A*. The state of affairs is identical with that of condition 2.

Conditions 7, 10, 15.—Same as condition 1.

Conditions 8, 12, 14.—Same as condition 2.

Condition 9.—Same as condition 3.

Condition 13.—Same as conditions 4 and 5.

Intermediate Positions of Keys.

There still remains, however, one other point which must be considered. Take, for instance, conditions 3 and 4. It will be seen that, at the beginning of 4, *B*'s key is already

down whilst *A*'s key is being depressed, and that there is therefore an instant of time in which *A*'s key is touching neither the front nor the back stop of his key. In this case the line current sent out by *B* passes along the line, through both coils of *A*'s relay in series, and through the rheostat to earth. The received current is therefore only half as great, because it has encountered twice the resistance. Since, however, it has passed through both coils of *A*'s relay the strength of the mark is unaffected. At *B* the line and compensation currents do not balance as they are of unequal strength. The compensation current therefore tends to space until *A*'s key touches the front stop.

Use of Non-polarized Relays and Direct Working.

In the exposition of this method standard relays have been depicted, but a little consideration will show that non-polarized relays or even a differentially wound sounder or inker for direct working might equally well have been employed.

Differential Galvanometer.

Before the combination or P.O. differential duplex is considered it will be advisable to describe the differential galvanometer, Fig. 101, employed in conjunction therewith. The two coils have each a resistance of 50Ω and each is shunted by a 300Ω resistance coil, the purpose of which (to reduce the self-inductance) is considered in Chapter IX (Wheatstone). The effect of the shunt is to reduce the combined resistance of each coil to 42·9Ω. The

Fig. 101.—Differential galvanometer.

magnetic needle is induced, and is either of the Varley or Spagnoletti type, and differs but little from the single needle dials previously described (page 177). In the older or Varley form the two-bar magnets were placed upon the lower sides of the coils instead of above them in order to economize the size of the case.

Upon each side of zero the scale is divided into degrees, and up to 30° the current is approximately proportional to the deflections produced. Using one coil only, or both in parallel, the value of one degree is $\frac{2}{3}$ m.a., which gives 20° = 8 m.a. and 30° = 12 m.a. Beyond this point the current required to produce a given deflection is much larger than $\frac{2}{3}$ m.a. per degree. For instance, 50° corresponds to 25 m.a. and 60° to 40 m.a. When the deflections are produced by the coils in series the currents are, of course, one-half the values given above.

The specified figure of merit of the instrument is 20 m.a., with which current, flowing through both coils in series a deflection of from 40° to 45° should be obtained.

P.O. or Combination Method of Duplex Working.

In the opposition method of duplex working the compensation circuit tended to space and the line circuit to mark. When the line path was stopped by the two batteries opposing each other the compensation circuits marked. The P.O. or combination method differs from this in the fact that when both keys are depressed the two batteries combine together in the line circuit. There is therefore twice as large a current in the line circuit as in the compensation circuit. The line coil of the relay tends to mark, and the signal is produced by the preponderance of the line current's effect over that of the compensation circuit at either end.

The internal apparatus connections are identical at the two ends of the circuit and the combination of the batteries is effected by reversing line and earth. In fact, just as in the case of every form of apparatus described, there is an up and a down line terminal whose connections to line and earth are determined by whether the office is an "up" or "down" station.

The single current key is connected between the strapped

terminals of the relay and the lower terminals of the galvanometer (Fig. 102). The small resistance coil r is equal in value to the internal resistance of the battery, and the resistance of the circuit is therefore the same in either position of the key. The method of joining up the key between the galvanometer and relay is often termed the "double split," a most unfortunate designation and one which frequently produces confusion in the minds of students. If a current divides between two paths it is evident that the two parts must re-unite at some point. In this case the current splits at the lower terminals of the galvanometer and re-unites at the strapped terminals of the

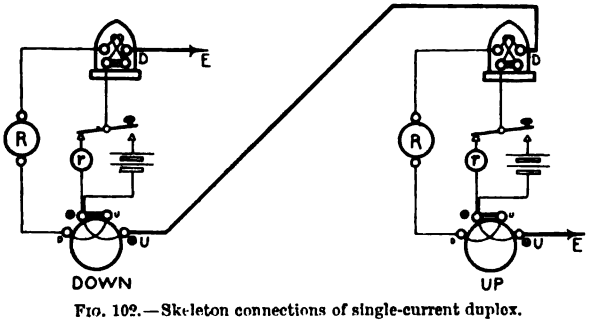

FIG. 102.—Skeleton connections of single-current duplex.

relay. The original object of the arrangement was to simplify the type of single and duplex switch. The rheostat contains resistance equal to that of the line and distant receiving apparatus, the latter comprising the right coil of the galvanometer, resistance block r,* and the circle coil of the relay.

PATH OF CURRENT.

After the detailed description of the conditions of duplex working given in the case of the opposition method it will, in the present instance, be unnecessary to do more than

* To be strictly accurate, account must be taken of the fact that "r" is shunted by the compensation circuit, and that the combined resistance of both is slightly less than "r". For all practical purposes this may however be ignored.

indicate the path of the current in each position of the keys.

When the down station depresses his key the current flows from the positive pole of the battery to the galvanometer where it divides equally, the line half going to earth, in at the up station's earth, through his relay *U*-circle to *D*-circle (producing a mark), through *r*, back-stop of the key, through the right or line coil of the galvanometer, along the line, through the *U*-circle *D*-circle coil of the down relay (*tending* to mark) back to the negative pole of the battery. The other half of the down station's current passes through the left or compensation coil of the galvanometer, through the rheostat and *D U* coil of the relay (*tending* to space) back to the negative pole of the battery. At the down station, no effect is produced upon the apparatus because the line and compensation currents are equal in value but opposed in effect. The mark and galvanometer deflection at the up station are due to the current received from the down station. At the down station the current splits at the galvanometer and the two parts re-unite at the strapped terminals of the relay. It should also be noted that although the current passes directly to earth at the down station, it has to traverse the resistance of the line and distant receiving apparatus before it can return to the down battery.

Upon depression of the up station's key, his current splits equally between the line and compensation circuits, and therefore produces no effect upon his own apparatus. The line half of the current passes along the line to the down station, through the *U*-circle *D*-circle coil of the relay (producing a mark), *r*, and line coil of the galvanometer to earth and thence back to the battery. As before, the mark is made by the current received, as in simplex working.

When both keys are depressed the batteries combine together in the line circuit, thus producing a current of twice the strength of that in each compensation circuit. The path of the line current is from the positive pole of the down station's battery through the line coil of the galvanometer, to earth, through the up station's *U*-circle *D*-circle coil of the relay, through the up station's battery (acting in the same direction), through the line coil of the galva-

nometer, along the line, through the down station's *U*-circle *D*-circle coil of the relay back to the negative pole of the battery. The direction of this current is from *U* to *D* in both relays and a mark is produced upon both. The path of the current in each compensation circuit is the same as before, but the current is in each case due to its own battery only and is therefore of the same strength. The line current, being due to the two batteries acting in series, is of twice the value, and the resultant effect is therefore equivalent to the current received when only one key is depressed.

Numerical Values of Current in each part of the Circuit.

The case will perhaps best be illustrated by a numerical example. In order to simplify the calculation the internal resistance of the battery and r will be taken as negligible. Let the resistance of each coil of the galvanometer be taken as 43ω, that of the line as 264ω, and each coil of the relay as 200ω—

Resistance in each rheostat = 264 + 43 + 200 = 507ω.
Total resistance of line circuit = 200 + 264 + 43 + 200 + 43 = 750ω.
Total resistance of each compensation circuit = 750ω.
Let the E.M.F. of each battery = 7·5.

Current in line circuit (both keys depressed) ... ... $= \frac{7{\cdot}5+7{\cdot}5}{750} = 20$ m.a.

Current in compensation circuits $= \frac{7{\cdot}5}{750} = 10$ m.a.

Current in line circuit (one key depressed) ... ... $= \frac{7{\cdot}5}{750} = 10$ m.a.

The received current when one key only is depressed is 10 m.a., and this passes through one coil of the receiving relay. When both keys are down the line coils of the relays carry 20 m.a. and the compensation circuits 10 m.a. The net effect upon the tongue of either relay is precisely the same as that produced when the distant station's key only is depressed.

Intermediate Positions of Keys.

The last condition which remains to be considered is the path of the current when one key is depressed and the other momentarily occupies a mid-way position. In this case the path of the current at the receiving end is through both coils of the galvanometer, through the rheostat and both coils of the relay. Taking the above figures, the

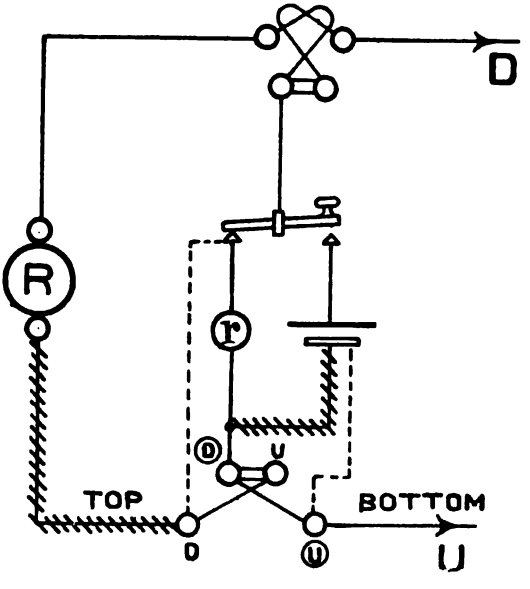

Fig. 103.—Alterations to single-current duplex connections required for simplex working. The scored connections are required for duplex and the dotted connections for simplex working. "Top" and "bottom" refer to arrangement of the duplex switch.

value of the current is 5 m.a., but as this passes through both coils of the relay its effect is the same as 10 m.a. upon one coil. At the sending end the current in the compensation circuit is as before 10 m.a. upon one coil tending to space, opposed by 5 m.a. upon one coil tending to mark. It will be therefore noticed that, whilst the combination method tends to end the mark instantly contact is broken

with the front stop of the key, the opposition method tends to prolong it until contact is made with the back-stop.

Skeleton Connections Required for Simple Duplex.

The connections depicted in Fig. 102 are the actual connections which are formed when the duplex and single switch is turned to the duplex position. It is, however, desirable to be able to revert to simplex working at will since it occasionally happens that line faults which will prohibit duplex will not stop simplex working. In order to convert the connections of Fig. 102 into those of the single current sounder (Fig. 89) the negative pole of the battery must be disconnected from the relay split and joined to *U*-circle. *D* of the relay must be taken off the rheostat and joined to the backstop of the key. These alterations are shown in Fig. 103, and it will be seen that they can readily be made by means of two two-way switches. The resistance coil *r* remains in circuit, and unfortunately acts as a shunt on the *U D* coil of the relay. Its effect is not of a very serious character, and it is only quite recently that, for universal working (Chapter XVI), a special and more complicated switch has been designed to disconnect it during simplex working.

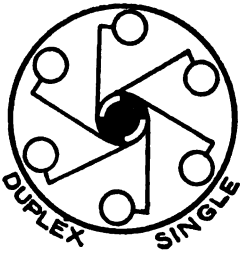

Fig. 104.—Duplex-switch arrangement of springs and contact pieces.

Duplex Switch.

The duplex switch (officially termed a 6-terminal 2-position switch) is essentially two two-way switches controlled by one lever. The six terminals are equally spaced round the wooden base of the instrument beneath which they are respectively joined to six brass springs. The springs rest upon a round piece of ebonite carrying two insulated segments of brass. In the position shown (Fig. 104), the bottom terminal and its left-hand neighbour are connected, whilst the top terminal and that to the right are also connected. When the handle is moved to the right, or

simplex, position the central portion moves with it, so connecting the springs then lying upon the two brass segments. The terminals between which the handle lies are connected, as well as those opposite (*vide* Figs. 105 and 106).

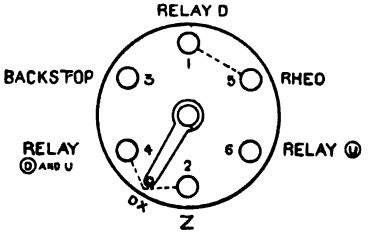

FIG. 105.—Duplex switch connections when the lever is turned to "duplex."

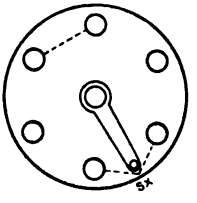

FIG. 106.—Duplex switch connections when the lever is turned to "single."

In a later form of switch the terminals are connected to six segmental pieces of brass arranged round the under-

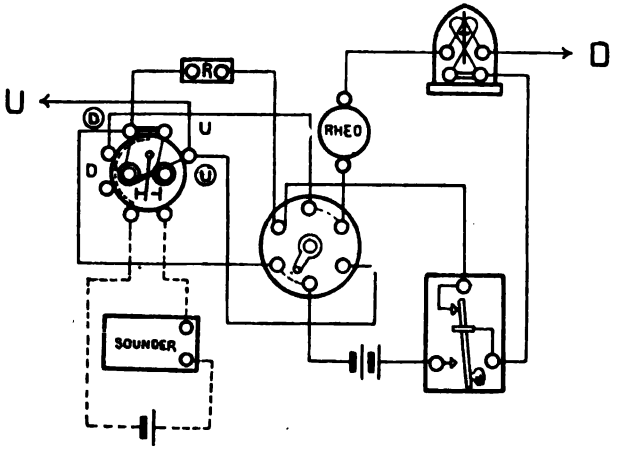

FIG. 107.—Connections of single-current duplex.

side of the switch and two insulated U-shaped pieces of brass, both mechanically connected to the switch lever, form the connections. The result is the same as in the older switch, but the arrangement is considerably simpler and cheaper.

Connections of Duplex Switch.

The connections made and broken by the duplex switch are clearly indicated by Fig. 105, and can be compared with Fig. 103. The full connections of the set are shown in Fig. 107.

Balancing.

If the home key only is depressed the tendency of the current in the line circuit is to mark and that in the compensation circuit to space. The direction in which the galvanometer needle deflects therefore indicates which of the circuits is carrying the larger current, and, consequently, whether the resistance in the rheostat is too high or too low. The principle to be adopted is to balance as nearly as possible with the 400$^{\omega}$ arm and then, leaving this arm at the lower value, to similarly deal with the 40$^{\omega}$, and, if necessary, use the 10$^{\omega}$ and 20$^{\omega}$ coils to obtain the accurate balance. The matter is, however, more fully dealt with in connection with the double-current duplex (see p. 262).

Faults.

A disconnection in the compensation circuit or an earth fault appearing upon the line causes the sender's signals to be registered at the sending end. A disconnection of the line circuit causes the sender's galvanometer to move in response to his key, but the marks are not received upon his sounder.

Faults in the apparatus are located by observing the conditions under which marks are, and are not, sent and received. It should be remembered that r shunts the U D coil of the relay at simplex, and that inability to work duplex whilst simplex working was possible could in this case be due to disconnection of the U D coil of the relay. The tracing of all the other faults is very similar to the methods needed in the double current duplex, and no further consideration will be given to the subject in this chapter.

Useful Facts.

The full connections will be readily memorized by the

aid of Fig. 103, but the following points will doubtless assist :—

1. Right side of galvanometer is the down-line terminal of the set.
2. *U*-circle of the relay is the up-line terminal of the set.
3. Positive pole of the battery is connected to the front stop of the key.
4. Line coil of the relay tends to mark and compensation to space.
5. Up station puts positive to line to mark.

The last two statements are chiefly valuable in checking the correctness of connections.

Direct Writer Duplex.

The direct writer is occasionally duplexed by winding the electro-magnet differentially, and by adding the requisite auxiliary apparatus. The current required is from 16 to 20 m.a., the coils being wound to a resistance of 200$^{\omega}$ each. As the instrument is directly worked no local batteries are needed. There are very few of these instruments in use, and detailed description is not justified.

Difficulty in Working Very Short Circuits.

It is not possible to work a duplex circuit through a line of very low resistance without special arrangements. For instance, it is impossible for satisfactory working to be obtained between two sets in the same office or over a circuit which is only one or two miles in length. The reason is that, in the ordinary arrangement, no account is taken of the self-inductance of the distant receiving apparatus. In the compensation circuit there is one coil of the relay, one of the galvanometer and a resistance equal to that of the line and one coil of the relay and one of the galvanometer at the distant end. In the line circuit there are, therefore, one coil of the home galvanometer, one of the home relay, the line itself, and one coil each of the distant relay and galvanometer. Whilst the compensation is equal in resistance to that of the line circuit, the self-inductance of the line circuit exceeds that of the compensation circuit by an amount equal to the self-inductance of one coil each

of the galvanometer and relay. In the majority of cases this lack of balance has no practical effect, but upon very short circuits it renders duplex working quite impossible owing to the false signals produced by working the key. In fact, the effect is similar but opposite in direction to the "kicks" due to unequal capacity in the line and compensation circuits dealt with in a subsequent section of the present chapter.

One solution of the difficulty is to artificially increase the resistance of the circuit to such a value that the E.M.F. of self-induction produces a current of negligible dimensions. This may entail the use of extra battery power, and the better plan is therefore to include in the compensation circuit a coil having a self-inductance equal to that of one coil of the relay and the coil of the galvanometer.

These remarks apply equally to double current duplex and to quadruplex working. In the latter system a special coil has been designed to meet the difficulty (see Chapter XVI).

Battery Power and Current Required.

The line battery is of the Large Daniell form and a current of from 15 m.a. to 20 m.a. is required. The local battery is either a 3-cell Large Daniell or a 2-cell Bichromate.

Although single current duplex working may be employed upon any circuit under 25 miles in length, there are very many circuits of far shorter length which are worked double current.

THE DOUBLE CURRENT SOUNDER DUPLEX.

The advantages which have been claimed for the double current system in conjunction with simplex (page 222), apply with even greater force to duplex, working. In fact, the number of single current duplex circuits in use at the present time is comparatively small, although there are very many cases where single current working could be quite satisfactorily employed.

Conditions for Double Current Duplex Working.

In the double current duplex a spacing current takes the place and performs the functions of the magnetic bias employed in single current working. Consideration will show that the following conditions must obtain :—

1. When both keys are at rest (switches to "send") the tongues of both relays must be held over to the spacing side.
2. When both keys are depressed (switches to "send") the tongues of both relays must be held over to the marking side.
3. When one key is at rest and the other depressed (switches to "send") the relay at the end where the key is depressed must space, and the other relay must mark.

Skeleton Connections.

When both keys are depressed the skeleton connections and values of the currents in each portion of the apparatus are identical with those of the single current system when the keys at both ends are down.

The general connections for double current duplex working differ from those of the single current duplex merely in the substitution (between the strapped terminals of the relay and galvanometer) of a double current for a single current key. The rheostat is joined between the left side of the galvanometer and *D* of the relay, and contains resistance equal to that of the line and distant receiving apparatus. *U*-circle of the relay and the right-hand terminal of the galvanometer are respectively the up and down line terminals, and these are connected to line and earth in accordance with the principles already stated.

When both keys are at rest or both are depressed, the two stations' batteries combine together to produce an effect upon both stations' relays. The compensation circuits in both these cases carry a current of half the value of that in the line circuit, because the current in the former case is produced by the two batteries in series, whilst in the latter the current is due to each battery acting separately. The effect upon the relay is due to the preponderance of the current in the line over those in the compensation circuits.

As this principle has already received ample consideration no further explanation should be necessary. It should also be apparent that when both keys are at rest the compensation circuit tends to space and the line circuit to mark.

When one key is depressed the battery at that end is reversed and consequently the direction of the current in its compensation circuit is changed. Instead of tending to mark it now tends to space and, since the reversal of the battery causes the two stations' batteries to oppose each other, it is left free to produce this effect. At the distant end the compensation circuit marks.

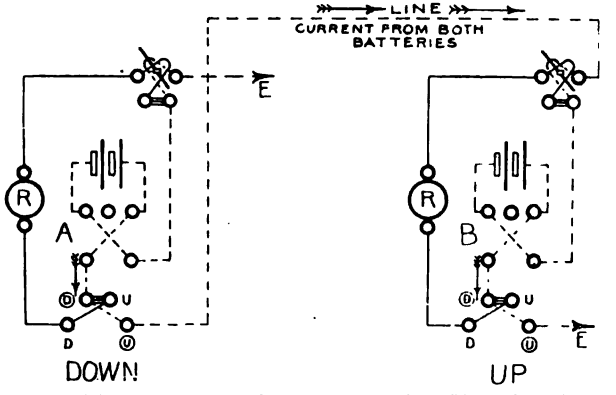

FIG. 108.—Skeleton connections of double-current duplex. The path of the current due to both batteries is shown by dotted lines and the compensation current by the full lines.

Both keys at rest or both depressed.—The skeleton connections of a double current duplex circuit (both keys at rest) are depicted in Fig. 108. The path of the line current has been shown by dotted lines and arrows, whilst the compensation circuits are shown by full lines. The line current is twice as great as the compensation current and, when both keys are at rest (as shown), passes through the circle coils of both relays in the direction *D* to *U*. If the current in each compensation circuit is 10 m.a. that in the line circuit in 20 m.a., whilst that in the battery from the galvanometer split to the relay split is 30 m.a., in each case. If both keys are depressed the direction of the

current is everywhere reversed and both relays will therefore mark. The strengths of the currents in the various parts of the circuit are, of course, the same as in the previous case.

One key only depressed.—The conditions which result when the down-station depresses the key whilst the up-station is at rest are shown in Fig. 109. In this case the two batteries have similar poles to line, and being of equal E.M.F., there is no current in the line circuit, therefore the compensation circuits are left unopposed. The paths

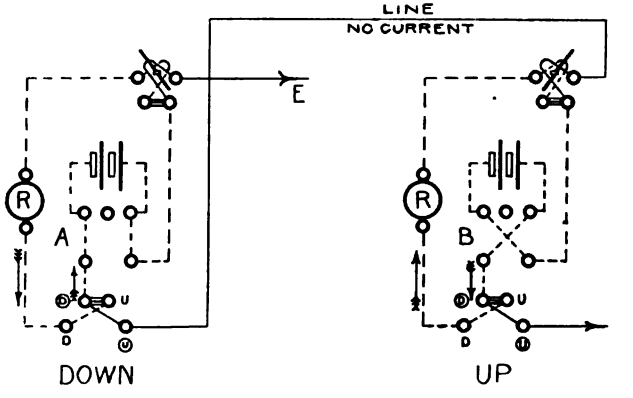

FIG. 109.—Skeleton connections of double-current duplex. The path of the current in the compensation circuit is shown by dotted lines. The full lines indicate paths in which there is no current flowing.

and directions of the currents have, in each case, been indicated by dotted lines and arrows. The full lines in this figure represent parts of the circuit in which no current is flowing.

EFFECT OF CAPACITY OF LINE.

In order to render duplex working practicable, it is essential that the compensation circuit shall resemble the line circuit as closely as possible. A long or underground telegraph line possesses considerable capacity as well as resistance, and therefore a rheostat alone is insufficient for

balancing. With short lines no provision need be made to balance the capacity and a rheostat is therefore all that is required in the compensation circuit.

It has been stated that a line has to be charged before any effect is produced upon the distant apparatus. Upon connecting an earthed battery to such a circuit there occurs a rush of current into the circuit to satisfy its capacity. If such a circuit were balanced only by a rheostat this rush of current into the circuit would momentarily upset the balance and so produce a "kick" upon the relay. During the time that the wire is being charged it behaves as though it offered little or no resistance to the charging battery. The resulting heavy rush of current into the line would preponderate over the steady current which would, almost instantly, commence through the compensation circuit—upon releasing the key the wire would discharge and a momentary upsetting of the balance would again result. It will be quite obvious that these irregularities of the sending current occurring in the middle of received marks would cause them to split and would be quite sufficient to preclude the possibility of duplex working upon long lines. It is therefore necessary to give to the compensation circuit an amount of capacity which will cause charges and discharges in that circuit equal in every respect to those of the line. This may frequently be accomplished by simply joining a condenser of the requisite capacity across the terminals of the rheostat. Later, it will be shown that this simple arrangement has to be considerably modified in the case of very long circuits. It will, however, amply suffice for the explanation of the paths and directions of the line and compensation circuit charge, discharge, and re-charge, under working conditions. Before proceeding further it will be necessary to show how the value and distribution of the charge upon a telegraph line may be represented.

Graphic Representation of the Charge upon a Line.

The quantity of electricity or the charge upon a disconnected telegraph circuit is equal to the product of its capacity and the E.M.F. applied to it. If, therefore, the capacity is numerically represented by the length of a

horizontal line and the E.M.F. by the height of a vertical line, the quantity of the charge will be represented by the area of the rectangle contained by those lines. Moreover, the direction of the charge, positive or negative, may be shown by drawing the rectangle respectively above or below the horizontal line. If an E.M.F. of one volt is represented by a vertical line one inch long and a farad by a horizontal line one inch long, the area enclosed is one square inch, and this would represent one coulomb. Any values of E.M.F. and capacity could readily be plotted, and the enclosed area in square inches would represent the value of the charge in coulombs. In the present case, however, it is only desired to show the relative magnitudes and distribu-

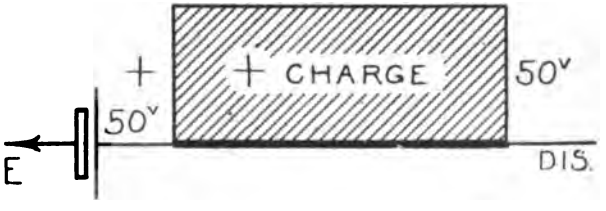

FIG. 110.—Positive charge upon a disconnected line.

tion of charges, and therefore 50 volts and $\frac{1}{2}$ m.f. will respectively be represented by $\frac{3}{4}$ and $\frac{7}{2\,0}$ inch. The value of the charge in coulombs will then be equal to $\frac{1}{5\,2\,5\,0}$ of the area enclosed (in square inches). The farad and coulomb are, of course, far too large units for practical purposes, and in this instance each square inch of area will represent twenty-five micro coulombs.

The charge due to an E.M.F. of 50v applied to a circuit of 5 m.f. capacity is shown in Fig. 110. The area of the shaded portion represents the value of the charge, and, as it is shown above the line, the sign is positive. Since the wire is disconnected the same difference of potential exists between line and earth at both ends of the circuit. It will also be seen that the charge was due to a current flowing from the positive pole of the battery, through the dielectric, to earth, and back to the negative pole of the battery. If the battery be now disconnected and the wire

earthed, the charge will flow out of the wire to earth and so relieve the strain upon the dielectric.

An E.M.F. of 50^{v} is shown applied in the reverse direction to an earthed circuit of 5 m.f. capacity in Fig. 111. In this case the potential of the positive pole of the battery

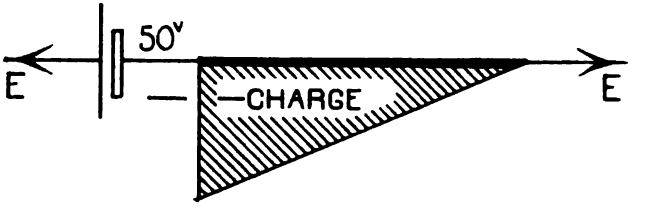

FIG. 111.—Negative charge upon an earthed circuit.

is zero, *i. e.* the same as that of the earth, whilst that of the negative pole is 50 volts below zero. At the battery end the difference of potential between the wire and earth is 50 volts, but at the other end it is nothing, since that end is earth connected. The charge is therefore represented in

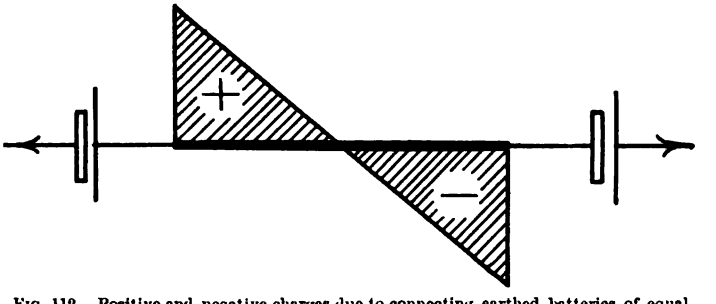

FIG. 112.—Positive and negative charges due to connecting earthed batteries of equal E.M.F., but with their opposite poles connected to the two ends of the circuit.

value by the area, and in sign by the *downward position* of the triangle. It will be seen that, with the same E.M.F. applied in both cases, the value of the charge upon an earthed circuit is half that upon the circuit when disconnected. It will also be noted that the charge is not evenly distributed over the wire but is densest at the battery end and at the distant end is nothing. The density

therefore varies from nothing at the earthed end to a maximum at the battery end, due, of course, to the fact that the difference of potential similarly varies from nothing to -50 volts.

The effect of connecting two earthed batteries in series at either end of a circuit is shown in Fig. 112. The differences of potential between each end and earth is $+50$ volts and -50 volts respectively. It will therefore be seen that at the centre of the circuit the potential is zero and no effect would be produced upon the magnitudes and values of the charges if that point were earthed. It will also be noticed that the disconnection of the right-hand battery would reproduce the conditions of Fig. 111, and that a current would flow into the wire sufficient to sweep out the negative charge and to charge the whole of the wire positively.

The results of the foregoing somewhat lengthy explanations may be summarized as follows, and it is in this form that they will be applied to the practical cases which present themselves.

1. The value and sign of a charge may be represented by the area of a rectangle or triangle as the case may be.
2. If either pole of a battery is earthed its potential is considered zero, and that of the other pole as the E.M.F. of the battery above or below zero as the case may be.
3. The potential of the earthed end of a circuit is considered as zero.

Paths of Line and Compensation Circuit Charges and Discharges.

When both keys of a double current duplex set are at rest opposite poles of the battery are connected to the line at the two ends and the distribution and signs of the charges are therefore similar to those depicted in Fig. 112. At the down station the positive pole of the battery is normally connected to line, but in Fig. 113 the key is shown depressed, *i.e.* with negative to line. The two shaded triangles represent the charges which exist when both keys are at rest. If the down station key were depressed, the negative pole of the battery would be connected to line as shown in the figure. It is, however,

desired to trace exactly what happens at the moment of depressing the key, and therefore the charges which existed when both keys were at rest have been depicted as stated. The up end of the line is negatively charged and the reversal of the battery at the down end will clearly produce a negative charge at that end also. Since the two batteries are of equal E.M.F. the potential below the earth will be the same, and the result will be that the wire will have the negative charge depicted by the rectangle enclosed by the wire, dotted lines, and the full line at the up end. In order to effect this, the existing positive charge at the down

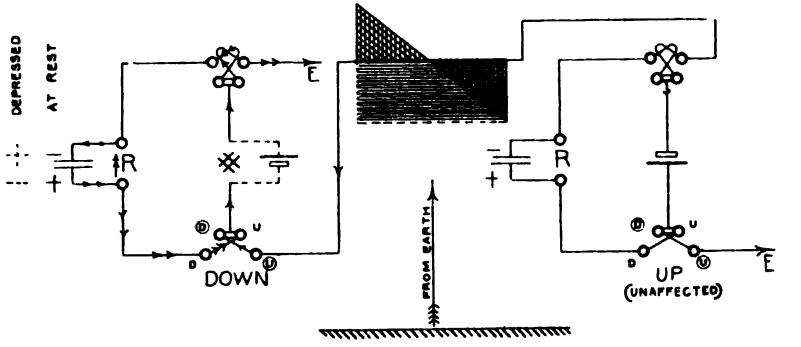

FIG. 113.—Double-current duplex. Paths of line and condenser charge and discharge. The conditions are depicted at the moment when the down key is depressed.

end must be swept out and a negative charge must be given of sufficient value to complete the negative charging of the wire. It should be noticed that the negative charge at the up end of the circuit remains the same, and it is merely a matter of "filling up" the rest of the wire with negative.

Having dealt with the charge when both keys are at rest and when the down key only is depressed it is necessary to trace the direction of the charges and discharges which must occur in order that the former condition may merge into the latter. In order to charge a wire negatively a current must flow from the positive to earth, through the dielectric to the wire and back to the negative pole of the battery. If the wire possesses a

positive charge the direction of its discharge is the same, viz. from the wire to earth through and in the same direction as the battery. In the present case, therefore, the depression of the down key (as shown in Fig. 113) causes the positive charge to discharge through the battery. The negative recharge of course takes place in the same direction. A positive discharge and a negative recharge current therefore flow from the wire through the *U*-circle *D*-circle coil of the relay (direction *U* to *D*), through the battery, right coil of the galvanometer, to earth. This may be put in another and more correct way. Upon reversing the battery a current flows from the positive pole through the galvanometer to earth, through the dielectric (air or gutta-percha as the case may be), on to the wire, out of the wire at the down end, through the circle coil of the relay, back to the negative pole of the battery. The current flows until the whole of the wire is negatively charged, and therefore the quantity of electricity flowing out of the end of the wire to earth through the apparatus is equal to the product of the E.M.F. of the battery, and the capacity of the circuit when disconnected at the distant end. This will be quite apparent from the fact that the charges existing when both keys were at rest are equal in magnitude, but opposite in sign.

The terminals of the rheostat are bridged by a condenser of such a capacity that its discharge and recharge in the reverse direction through the compensation coils of the relay and galvanometer are equal to the discharge and recharge of the line through the other coils. When both keys are at rest the condenser at the down station is charged by the difference of potential across the terminals of the rheostat; due, of course, to the current flowing in the compensation circuit. The lower plate is therefore charged positively and the upper negatively. When the down key is depressed (as depicted) the condenser discharges and is charged in the reverse direction, the result being indicated by the dotted signs. There are two paths open to the discharge current, viz. through the rheostat and through the *D U* coil of the relay, battery, and left coil of the galvanometer. By far the greater portion takes the latter path and is followed by the recharge in the reverse direction. In fact no serious error is made in assuming that the whole of

the discharge and recharge occurs through the relay and galvanometer, and that practically no current flows through the rheostat until the condenser is fully charged with the quantity of electricity it will require to have due to the potential difference between the terminals of the rheostat. The charges in the condenser at the up end are unaffected because that battery has not been disturbed, and therefore the potential difference across its rheostat is unaltered in magnitude or direction. Both the condenser and the line discharges and recharges are caused by the reversal of the battery and the circuit from the strapped galvanometer to the strapped relay terminals is common to both. The directions and paths of the line and condenser charges have respectively been indicated by single and double arrow-heads. The effect of the line charge is to produce a marking "kick" on depressing the key and that of the compensation circuit a spacing "kick," and by, choosing a suitable value of capacity in the condenser, the two effects counterbalance each other and duplex working is possible.

As the above conditions have received such minute consideration it will suffice to briefly state the effects due to depressing or raising the other key and then to summarize the whole of the results of the investigation.

If the down key is released the conditions of charge represented by the triangles will be re-established and the condenser will be discharged and recharged as indicated by the full and not the dotted signs. This will entail rushes of current in the down station's line and compensation circuits in directions opposite to those shown by the arrow-heads. The up station will be unaffected.

The depression of the up key whilst the down key is at rest will cause the whole of the line to be positively charged and will reverse the charge in the up condenser. The path of the line negative discharge and positive recharge is from the positive pole of the battery through the line coil of the galvanometer to line, through the dielectric, to earth, through the relay from *U*-circle to *D*-circle and back to the negative pole of the battery. The condenser discharges and recharges through the other coils of the galvanometer and relay, but in the spacing direction. The down station is unaffected. When the up key is released the conditions

previously existing are restored by discharges and recharges in the opposite direction to those just described.*

Summary of Effects of Line and Compensation Circuit Charges and Discharges.

The results of the foregoing investigations may be summarized as follows:—

1. At the end of the circuit, where the position of the key is unaltered, no effect takes place, and it is therefore only necessary to consider the end where the key is changed in position.
2. The sign of the charge upon the end of the line is the same as that of the pole of the battery connected to it.
3. The discharge and recharge of the line is in the same direction as the discharge and recharge of the condenser, and both are always in the same direction as the E.M.F. of the battery when the latter is changed by altering the position of the key.
4. The line discharge and recharge passes through the line coils of the relay and galvanometer and through the battery.
5. The compensation circuit charges and discharges through the left coil of the galvanometer, battery, and *U D*-coil of the relay.
6. On depressing a key the direction of the line discharge and recharge is from *U*-circle to *D*-circle, so tending to cause a marking kick. The galvanometer needle similarly upwards or towards the right.

Arrangement of Compensation Circuit for Balancing Long Lines.

Upon page 249 it was stated that very long lines could not be satisfactorily balanced by simply placing a condenser across the terminals of the rheostat. It will now be necessary to investigate this statement and consider the arrangements adopted in such cases.

The quantity of electricity in a given condenser depends upon the E.M.F. with which it was charged and upon its

* The reader is strongly advised to sketch each of the conditions dealt with, and to plot the resulting charges together with the paths of the current producing them.

capacity. The discharge of the condenser will give rise to a current of electricity, but the duration and magnitude of the current will depend upon the properties of the circuit through which it discharges. For instance, the condenser will take twice as long to discharge itself through a resistance coil of 100" as it would through a 50" coil. In the former case the average value of the discharge current would be only half as much as in the latter case.

In order that the discharge of the condenser in the compensation circuit may balance that in the line circuit, it is obvious that the discharges must not only be equal as regards the quantity of electricity discharged, but the discharges must occupy exactly the same time. In fact, at any and every instant during which the two discharges take place they must be exactly equal in value. Now the charge and discharge of a long line cannot be balanced by a compensation circuit arranged as in Fig. 113. The quantity of electricity discharged through the line coils of the galvanometer and relay may be exactly equal to that discharged through the compensation coils, but unless the rate of discharge is the same, irregularities will inevitably occur. The line charge and discharge are slow in comparison with the charge and discharge of a condenser arranged as described. The reason is that in charging a line, say a hundred miles long, the current has to traverse and charge the first ten miles before it can charge the second, the second ten miles of line has to be traversed and charged by the current before the third ten miles is charged, and so on. The resistance encountered in the path of the charging current slows down the rate at which the circuit is charged. In the case of the condenser the battery is applied almost directly to its terminals and the charge is therefore much more rapid. In the one case the capacity is distributed over a very long line, every mile of which has a very appreciable resistance, whilst in the other the capacity is all located at one point and that point almost directly between the terminals of the charging battery. The one coil of the relay, and the one coil of the galvanometer alone intervene between the terminals of the battery and the condenser.

Effects of Defective Capacity Balance.

It will now be possible to trace the effect of attempting to balance a long line by a condenser bridged across the rheostat. In Fig. 113 the paths and directions of the line and condenser discharge and recharge upon depression of the down key are indicated by arrow-heads. If the line is very long, its discharge and recharge will occupy a longer time than that of the condenser. The rapid charging of the condenser will give rise to a short heavy current whilst the slow charging of the line will entail a smaller current spread over a longer time. Therefore the charge current through the compensation circuit will, during its existence, preponderate over the line charge current, so causing a kick to spacing. Immediately the short heavy charge of the condenser ceases the line charge, which is still proceeding, in its turn affects the relay, but in the opposite direction. The result of the arrangement is that the two charge currents alternately upset the balance, but the unopposed latter part of the line charging current is of very small importance in comparison with the preponderance of the short heavy rush of current through the condenser.

The introduction of resistance into the charging and discharging circuit of a condenser slows down its rate of charge and discharge. If, for instance, an E.M.F. of 100 volts is applied to a condenser in series with a resistance of 10,000$^{\omega}$, it will be obvious that the maximum possible value of the charging current at the instant at which the charge commences cannot possibly exceed 10 m.a. $\left(\frac{E}{R}\right)$. If the resistance is 1000$^{\omega}$, upon the same argument the maximum current could not exceed 100 m.a.

The insertion of resistance between the condenser and the rheostat has, then, the effect of slowing down the charge and discharge of the condenser. It will not, however, in any way affect the *quantity* of electricity in the condenser.

Retardation and Condenser Coils.

Upon very long circuits even this device fails, and recourse

is taken to the use of two condensers and two resistances as depicted in Fig. 114. The first condenser A is charged and discharged through the resistance R_2 and the second conenser B through both R_2 and R_3. The charge and discharge of the second condenser therefore occur a little later than those of the first, and the result is a much closer imitation of the line charge and discharge than is possible with a single condenser. The two condensers are contained in a single box as described in Chapter VI. A reference to this and to Figs. 114 and 115 will make the arrangement adopted quite clear.

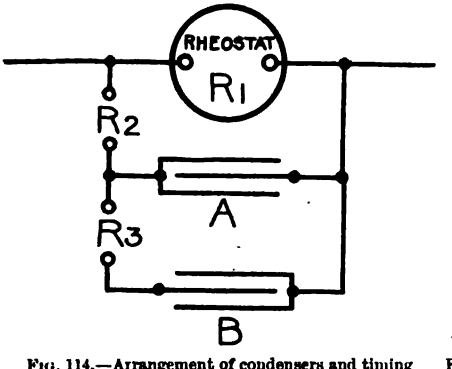

FIG. 114.—Arrangement of condensers and timing resistances in the compensation circuit.

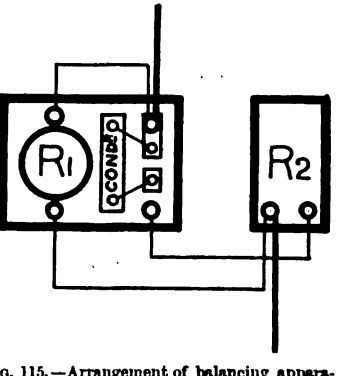

FIG. 115.—Arrangement of balancing apparatus in compensation circuit. R_1 is the rheostat, R_2 the retardation coils, and R_3 (Fig. 114) and the coils marked "condr." (Fig. 115) are the condenser coils.

The resistance R_2 is termed the retardation coils and is furnished with eight coils having a total maximum of 1100$^{\omega}$, the smallest coil being 10$^{\omega}$. The resistance R_3 is only employed upon circuits over 150 miles in length, and for circuits under 200 miles long consists of a fixed resistance coil of 2000$^{\omega}$. Over that length an 8-plug resistance box, having a range of 50$^{\omega}$ to 4050$^{\omega}$ by gradations of 50$^{\omega}$ is employed and is termed the "condenser coils." Since the resistance required in the condenser coils varies to a very small extent with the weather, the fixed resistance coil 2000$^{\omega}$ is quite satisfactory upon any but the longest circuits.

For cable circuits it is necessary to employ a three-section or triple condenser of considerable capacity and three sets of resistance coils, but the principle of the arrangement is identical with that of the two-section condenser.

Capacity Balance may Differ at the Two Stations.

In Fig. 113 the capacity and resistance of the line were assumed to be uniformly distributed along the length of the line. In practice this is rarely the case, especially upon long circuits. The effect of an unequal distribution is to alter the position of the zero point. To take a greatly exaggerated case, suppose that a line has a resistance of 2000$^{\omega}$, and that one-half of the circuit has a capacity of 15 m.f., whilst the capacity of the second half is nothing. Such a case could be artificially produced by adding a resistance coil to a long underground circuit, the value of the coil being equal to the conductor resistance of the line. The zero point of the circuit would be at the junction of the line and the coil. Since there is no charge upon the artificial resistance, it will be found that the effect of reversing the key at the resistance coil end of the circuit is to cause a charge proportional to the area of the triangle representing the charge to occur. At the cable end, reversal of the key results in a discharge exactly three times as great. This deduction from the principles already considered is so obvious that further explanation should not be needed.

The application of this principle in practice shows that where a circuit consists of a submarine or long underground line at one end, with an open line of considerable length joining it, the capacity at the open end of the circuit may be very much less than that at the cable end. For instance, upon a London Birmingham duplex passing through the underground route $7\frac{1}{4}$ m.f. condensers are required at either end. If the circuit is extended Northwards from Birmingham by a long open line, a $10\frac{1}{2}$ m.f. condenser is needed at the London end.

At the cable end of a circuit the value of the retardation resistance is usually low, and the capacity in the first division of the condenser is correspondingly high.

Connections of Duplex Set.

A duplex and single switch is added to the apparatus in much the same way as in the single current sounder. The alterations required to change the set from duplex to simplex are shown in Fig. 116. The dotted lines represent

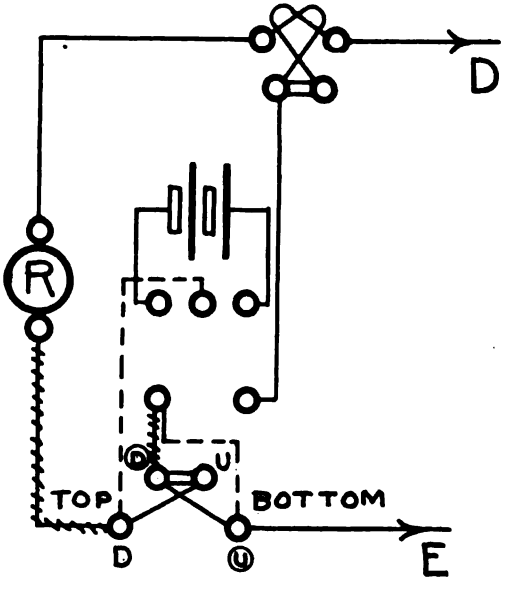

Fig. 116.—Alterations to double current duplex connections required for simplex working. The scored connections are required for duplex, and the dotted connections for simplex working.

the connections which must be established and the scored lines those which must be broken. Figs. 103 and 116 should be carefully compared, and little trouble will then be experienced in remembering the connections. The full connections are depicted in Fig. 117.

The following facts may profitably be noted :—

1. As in all types of sounder circuit, the up station sends positive to line to mark.

2. The right terminal of the galvanometer and the *U*-

circle terminal of the relay are respectively the down and up line terminals.

3. The top three terminals of the duplex switch deal with *D* of the relay, and the lower three with the left terminal of the key.

4. The key is inserted between the strapped terminals of the galvanometer and relay.

5. With the keys at rest the line, or circle, coils tend to space.

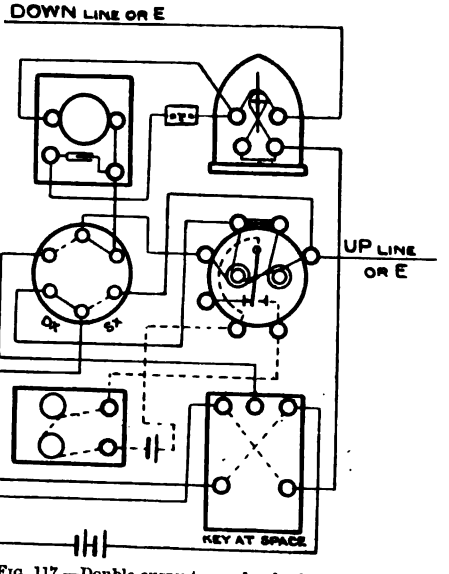

FIG. 117.—Double current sounder duplex connections.

RESISTANCE BALANCE.

It has previously been stated that the resistance of a conductor varies with its temperature. The conductor resistance of a telegraph circuit therefore varies from day to day, and the difference between its resistance at summer and winter temperature (100° F. and 22° F.) would amount to 26½% if the wire were of iron and to nearly 18% if of copper wire erected upon poles. The insulation resistance of the circuit is also subject to wide variations. In

very fine dry weather the insulation rises to a very high value, and in damp or wet weather falls to a corresponding extent. Upon long circuits this difference is most distinctly felt, but upon very short circuits it is not noticeable, because of the disparity in the values of the conductor resistance and the lowest value of the insulation resistance without the existence of a definite fault or faults. This point will not, perhaps, be clearly apprehended until Chapter XIX has been considered.

Since the resistance of a circuit is variable, it will be seen that an adjustable resistance and not a resistance coil of fixed value must be employed to balance it. The instrument employed, termed a rheostat, has been described in Chapter III. The value of the resistance which it is necessary to insert to obtain a balance is ascertained by means of the duplex set itself.

The top of the needle of all Post Office galvanometers deflects in the direction in which the effective current passes from terminal to terminal of the instrument, and reference to Figs. 108 and 109 will, by aid of this rule, show that a spacing current is represented by a deflection to the left, and a marking current by a right deflection. In Fig. 108 both needles deflect to the left, and the relay spaces by the preponderance of current in the line coils of the galvanometer and relay. This fact may be expressed in an equally correct but more convenient way, viz. that they are actuated by the current received from the distant station. If a resistance coil equal in value to the internal resistance of the battery is substituted for the distant battery, the deflection upon the home galvanometer at once falls to zero if the circuit has been accurately balanced. The home current divides equally between the line and compensation circuits, and no effect is therefore produced. If these circuits were not balanced then the one of lower resistance would carry the larger current, so producing a deflection, the direction of which would be reversed upon depression of the key. The effect of replacing the resistance coil by the distant battery may be regarded as the sending of a current through the home line coils of galvanometer and relay. This spacing current deflects the galvanometer and causes the relay to space, but if the home key is now depressed the deflection upon the

home galvanometer is increased or decreased according to which circuit (line or compensation) has the higher resistance.

If no resistance is inserted in the rheostat the compensation current is sufficiently great to overcome the effect of the current in the line coils of the relay and galvanometer, and a marking current and deflection will result. The sounder will be held down, and the marks sent upon the home key will be received reversed upon the home sounder. Upon the other hand, a disconnection or the insertion of a very large resistance in the rheostat will cause the marks from the home key to be received straight.

The practical operation of balancing is carried out by the aid of the effects which have been explained above. The 40ω arm of the rheostat is placed at zero, and the 400ω arm at any value in excess of the resistance of the circuit. The key is depressed, and the effect observed upon the galvanometer or the sounder if the balance is out to a sufficient extent to affect it. The 400ω arm is moved downwards, point by point, until the depression of the key gives a deflection in the reverse direction to that previously obtained. The 40ω arm is then moved up point by point until a balance is obtained. An increased downward deflection or a reduced marking deflection upon depression of the key indicates that the resistance in the rheostat should be reduced and the converse that it should be increased. The use of this rule in a logical manner enables a circuit to be accurately balanced in the minimum of time.

Capacity Balance.

The balancing of the capacity of the circuit can only be effected when the resistance has been dealt with, and it will now be necessary to point out that the resistance balance is obtained by noting the position of the galvanometer needle when the kicks due to inaccurate capacity balance have passed away. It is merely necessary to hold the key down sufficiently long for the needle to come to rest after the kick has passed away. The steady positions of the needle should alone be observed in this case.

The effects of capacity have been very fully considered,

and the following rules can readily be deduced from the previous explanation :—

1. If, on depressing the key, the galvanometer needle momentarily deflects upwards (*i. e.* marking direction), the capacity in the compensation circuit should be increased.

2. If, on depressing the key, the galvanometer needle momentarily deflects downwards (*i. e.* spacing direction), the capacity in the compensation circuit should be decreased.

3. If, on depressing the key, the galvanometer needle momentarily deflects upwards, and upon releasing the key again momentarily deflects in the same direction, the timing resistances (retardation and condenser coils) require alteration.

In cases (1) and (2) the kick is observed in the reverse direction when the key is released. The final adjustments are frequently made by the passage of working signals, and resolve themselves into an intelligent form of "trial and failure" method. The time taken in finding the exact balance of a cable circuit upon which a triple condenser is employed is very considerable, but when once found the variations necessitated from it are confined within small limits.

Faults.

A disconnected line causes the sender's marks to be received reversed upon the home apparatus, and this still happens when the rheostat resistance is increased. The deflection upon the galvanometer will be reduced as the resistance is increased.

An earth upon the line reduces the normal deflection upon the home galvanometer, and when the switches at both ends are turned to simplex, the deflection when sending greatly exceeds that when receiving. The resistance in the rheostat is also greatly reduced.

Apparatus faults are located by application of the principles previously laid down, but one or two examples of the effects of such faults are appended.

If it is possible to work duplex and not simplex, or *vice versa*, the fault may be caused by a disconnection in the parts of the circuit not used under the condition (simplex or duplex working) which is defective, but not by a disconnection in the parts which *are* used. The parts of the

circuit included in the path of the current for the perfect condition are therefore eliminated from consideration. The location of the defect is so similar to that adopted with the single current duplex that it will only be necessary to specify faults which are peculiar to the double current duplex.

Disconnection of the condenser is revealed by split marks, and the fact that alteration of the plugs produces no effect. A short circuit in the condenser renders the rheostat inoperative, and the sender's marks are received reversed.

A rather puzzling fault which occasionally occurs is due to one of the shunts across the galvanometer coils becoming disconnected. The result is that when a balance has been obtained by the galvanometer the working signals are split up when both stations are simultaneously working. This is immediately detected if the signals are rectified by altering the resistance in the rheostat. The signals are then correctly received, but the home key causes the galvanometer to deflect.

A similar fault is occasionally produced by the insulation of the galvanometer or the relay coils giving way, and so short circuiting a number of turns of wire.

A heavy loss upon a circuit frequently precludes duplex but not simplex working. When a wire is earthy, its resistance, and consequently the resistance required in the rheostat to balance it, is greatly decreased. The strength of the current in both line and compensation coils is therefore correspondingly increased, but these two effects balance. If, now, three-fourths of the current from the distant station flow to earth one-fourth only will be available at the distant end. This fraction of the current acts solely upon one coil of the relay, whereas in simplex working the current would pass through both coils of the relay in series. The pull upon the tongue of the relay would be quite twice as strong in the latter as in the former case.

Battery Power and Current Required.

Large Daniells are employed upon all double current simplex circuits under 150 miles in length, and Bichromates above 150 miles. The current required is from 14 to 17 m.a., and is calculated for the conditions of simplex working. The local battery is either a three-cell Large Daniell or a two-cell Bichromate.

CHAPTER VIII

THE QUADRUPLEX.

QUADRUPLEX working consists in the simultaneous transmission of two messages in each direction over a single wire connecting two stations. It is accomplished by taking advantage of the fact that currents may differ from each other in direction and in strength. Two keys are employed, viz. the reversing key which determines the direction of the current and the increment key which determines its strength. One of the two relays used in conjunction is polarized and the other non-polarized. The polarized relay is of the Post Office Standard *B* pattern, in which the tongue is, of course, only moved over to *M* when the current passes in the direction *U* to *D*. The non-polarized relay, upon the other hand, is actuated by a current in either direction provided that it is sufficiently strong to overcome the pull of the antagonistic spring. This relay is so adjusted that unless the strength of the current is increased by depression of the increment key its armature is unaffected. The polarized relay is only affected by a current in the direction *U* to *D* which occurs solely when the reversing key is down.

It will therefore be seen that the two relays may be selectively actuated by the two keys. By depressing the reversing key a current passes through the relays in the direction *U* to *D*, but it only actuates the polarized relay, its strength being insufficient to overcome the pull of the spring upon the non-polarized relay. Depression of the increment key alone, only actuates the non-polarized relay because the current passes in the direction *D* to *U*. If both keys are down a current of full strength passes through both relays in the direction *U* to *D* and both are therefore actuated.

The whole arrangement is duplexed upon the differential principle by splitting the sending currents equally through the differentially wound relays and galvanometer. The details of the instruments will, however, be reserved until the working of the set as a whole has been considered.

Skeleton Connections.

The skeleton connections of a quadruplex set are depicted

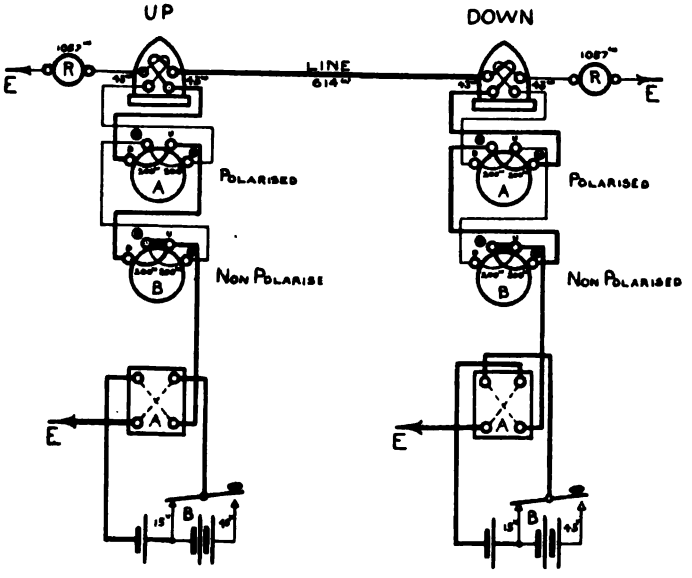

Fig. 118.—Principle of Quadruplex.

in Fig. 118. The reversing key is similar to the double current key but with the switch omitted. Its connections when at rest and depressed are identical with those of the double current key, with the switch to send, under the same conditions. The increment key is here represented by an ordinary single current key and at present calls for no further comment. The negative pole of the battery is joined to *Z* of the reversing key and *C* is taken to the centre of the increment key. When this key is at rest only

a part of the battery is connected to the reversing key, but when it is depressed the whole battery is so connected. The reversing key controls the direction of the current and the increment key its strength.

The left side of the reversing key is earthed and the right side goes to the split of the non-polarized relay. The right-hand coil of the galvanometer, the plain coil of the *A* side relay and the same coil of the *B* side relay are connected in series to the line at the up station. The other coils of the two relays and galvanometer are similarly joined in series to the rheostat which contains resistance equal to that of the line and distant apparatus.

When all the keys are at rest the conditions which obtain are similar to those of a double current duplex, viz. the batteries at the two stations combine together to produce a current in the line circuit twice as large as that in either of the compensation circuits. This preponderating current must be in the spacing direction, and in order to effect this and the combination of the batteries, the connections at the down office have to be modified. Firstly, to effect the combination of the batteries the two battery wires upon *Z* and *C* of the reversing key are crossed, and secondly the line and rheostat change sides of the galvanometer and thus a spacing effect is normally produced at the down office.

Value of the Current under various conditions.

The working of the set will be most clearly understood by giving definite numerical values to the various factors which determine the currents in the various parts of the circuit. With the *B* key at rest an E.M.F. of 15 volts is connected to the *A* key and with the *B* key depressed this E.M.F. is raised to 45 volts. The battery has been assumed to have no internal resistance in order to simplify the calculations involved. This assumption does not involve any appreciable error in the general results which will be obtained, but it will subsequently be indicated how far these results must be modified to accord with strict accuracy. The resistances of the remaining parts of the circuit are clearly marked upon the diagram (Fig. 118).

The total resistance of the line circuit is $200 + 200 + 43 + 614 + 43 + 200 + 200 = 1500^{\omega}$. The resistance of

either compensation circuit is $200 + 200 + 43 + 1057 = 1500^{\omega}$. With all the keys at rest the path of the line circuit current is from the positive pole of the 15-volt up battery to earth, through and joining with the 15-volt down battery through the line coils of both relays (direction *D* to *U*) and the galvanometer, along the line through the line coils of the up galvanometer and relays (*D* to *U*) and thence back to the negative pole of the battery. The current in this circuit is produced by $15 + 15 = 30$ volts and is therefore $\frac{30}{1500} = 20$ m.a. The compensation currents are each $\frac{15}{1500} = 10$ m.a. and in the direction *U* to *D*, consequently both *A* relays are held to spacing by the 10 m.a. preponderance of the line current from *D* to *U* in the relay. The *B* relays are unaffected because they are adjusted to be unaffected by a preponderance of 10 m.a. This is practically identical with the double current duplex, and it will therefore readily be seen that with both *A* keys down both *A* relays will mark due to the reversal of the current. With one *A* key down and one at rest the batteries oppose and their compensation circuits respectively space and mark with the 10 m.a. which their own batteries produce in them. As stated above, this current of 10 m.a. upon one coil of the relay, is not sufficient to actuate the *B* relays.

If both *B* keys are depressed an E.M.F. of 45 volts is connected to the *A* key at each end. With both the *A* keys at rest the paths and directions of the currents are identical with those described when the *B* keys were also at rest. The strength of the current in each part of the circuit is, however, three times as great.

$$\text{Line circuit current} = \frac{45 + 45}{1500} = 60 \text{ m.a.}$$

$$\text{Compensation circuits' current} = \frac{45}{1500} = 30 \text{ m.a.}$$

The current in the line coils of both stations' relays is from *D* to *U* and therefore both *A* relays space, but the *B* relays, being non-polarized, both mark due to the effect of $60 - 30 = 30$ m.a. upon one coil of the relay.

If an *A* key is depressed whilst both *B* keys are still

down the batteries oppose each other in the line circuit, and the compensation circuits are therefore left unopposed to produce their effects. Each carries a current of 30 m.a. produced by the full power and therefore both *B* relays are actuated. At the end where the *A* key is depressed the current is in the direction *D* to *U* and therefore the *A* relay spaces, but at the distant end a mark is registered because the compensation current is there flowing in the *U* to *D* direction.

The two cases which remain to be considered are, firstly, when one *B* key only is depressed, and, secondly, when one *B* key and the distant *A* key are simultaneously depressed. In the first case the E.M.F. acting in the line circuit is $15 + 45 = 60$ and the current is therefore $\frac{60}{1500} = 40$ m.a. The direction of the line current is from *D* to *U* and is produced by the batteries acting together. At the end where the *B* key is depressed the compensation current is $\frac{45}{1500} = 30$ m.a. and the net effect at that end is therefore $40 - 30 = 10$ m.a. in the direction *D* to *U* through both relays. Both relays therefore space at this end. At the distant end the compensation current is produced by the smaller E.M.F. and is $\frac{15}{1500} = 10$ m.a. The net effect is therefore $40 - 10 = 30$ m.a. upon the line coil of the relays. This actuates the *B* but not the *A* relay because the direction of the current is from *D* to *U*.

The second case is rather more difficult to deal with. It is when one *A* key and the distant *B* key are depressed. Let the up *A* key and the down *B* key be depressed. The current in the line circuit is due to the larger down battery sending a current through the smaller up battery. This current is equal to the difference in the E.M.F.s divided by the resistance of the line circuits. It is $\frac{45-15}{1500} = 20$ m.a. in the direction *U* to *D* at the down and *D* to *U* at the up office. The compensation currents at the up and down offices are respectively 10 m.a. direction *D* to *U* and 30 m.a. direction *U* to *D*. At the down office the difference between the compensation and line currents is $30 - 20 = 10$ m.a. in

the direction *U* to *D*. The down *A* relay therefore marks, but the *B* relay is unaffected. At the up station the line current (20 m.a.) flows through both relays in the direction *D* to *U*. The current in the compensation circuit is 10 m.a. and in the same direction, viz. *D* to *U*. The effects of the line and compensation currents (20 m.a. and 10 m.a. respectively) are therefore added together, and are equivalent to 30 m.a. upon one coil of the relay. The *A* relay is unaffected, but the *B* relay is actuated.

In explaining the above condition it was stated that the larger battery sent a current of 20 m.a. through the smaller one. This statement is scarcely correct since the smaller battery is at the same time assumed to be sending a current through its compensation circuit. The numerical values of the currents obtained by the assumption are accurate, but the actual path of the current is this: the 20 m.a. flowing through the line circuit divides into two equal parts when it reaches the split of the relay, one of which parts flows through the battery in opposition to its E.M.F. and the other half flows round the compensation circuit.

The "*B* Kick."

A serious difficulty occurs in quadruplex working due to the fact that the reversal of the current through the circuit occupies a definite interval of time. The direction of the current in the line circuit is reversed if the *A* key is depressed whilst the *B* key is down. Since the continuous depression of the *B* key is actuating the distant *B* relay by the current sent over the line, the depression of the *A* key (also) entails an instant in which the distant *B* relay is unmagnetized. The spring upon the *B* relay therefore acts, and the tongue momentarily returns to its normal position, thus producing a break in the signal. This effect, generally termed the "*B* kick," is of vital importance, and the various systems of quadruplex differ almost solely in the method in which its deleterious effects are counteracted. Having described the effect in general terms it will be desirable, in view of its importance, to consider it in a more detailed manner.

Assuming the same figures as those previously employed the current in the line circuit is 60 m.a. when all the keys

are depressed. The compensation currents are, under the same circumstances, 30 m.a. in each case, and the *B* relays therefore are both actuated by the preponderance of the line current, whilst the *A* relays are actuated because the direction of the current is from *U* to *D*. If now the down station releases the *A* key the down battery is reversed. The current in the line circuit is stopped, and the current in the down compensation circuit is reversed in direction. These changes occupy a definite interval of time which varies with the capacity and resistance of the circuit. The reader's attention is directed at this point exclusively to the *B* relays. Since both the *B* keys are depressed both *B* relays should be continuously actuated, and the movements of the *A* keys must have no effect whatever upon the *B* sounders if quadruplex working is to be successful. At the down station the release of the *A* key stops the line current and reverses the direction of the magnetization of the coil of the *B* relay in the compensation circuit. With this *A* key down the preponderating line current actuated the down *B* relay, whilst, in the normal position, the *B* relay is actuated by the current in the compensation circuit. It will therefore be seen that the current in the compensation circuit has to change from 30 m.a. in one direction to 30 m.a. in the opposite direction. In changing there is clearly a moment at which the relay is entirely unmagnetized, and at this instant the spring will cause the relay tongue to break contact. This splits the mark which should continue uninterrupted so long as the up *B* key is depressed. At the up end of the circuit the compensation circuit is unaffected, but the line current has to fall from 60 m.a. to nothing, and in doing so there must clearly be an instant at which its value is 30 m.a., and therefore the up *B* relay also kicks, but this effect is quite small in comparison with that at the down office where the reversal of the *A* key has occurred.

One other example of the *B* kick will perhaps suffice for the complete elucidation of the effect. If the up *B* key is alone depressed the down *B* relay marks owing to the preponderance of the 40 m.a. in the line circuit over the 10 m.a. in the compensation circuit. During the depression of the up *B* key let the *A* key also be depressed. The reversal of the up battery reverses the direction of the current in the line circuit, and its final value is 20 m.a.

For the current to change from 40 m.a. in one direction to 20 m.a. in the reverse direction through the line occupies a definite interval of time, and at some instant before reversal during the change its value will have fallen from 40 m.a. to 10 m.a. At this instant the currents in the line and compensation circuits at the down station balance each other, and the relay is momentarily demagnetized. The spring upon the *B* relay tongue breaks the mark which the permanent depression of the up *B* key should have rendered quite continuous.

The conditions described above are depicted in Fig. 119, but the keys, galvanometers, and *A* relays have been omitted in order that attention may be concentrated upon

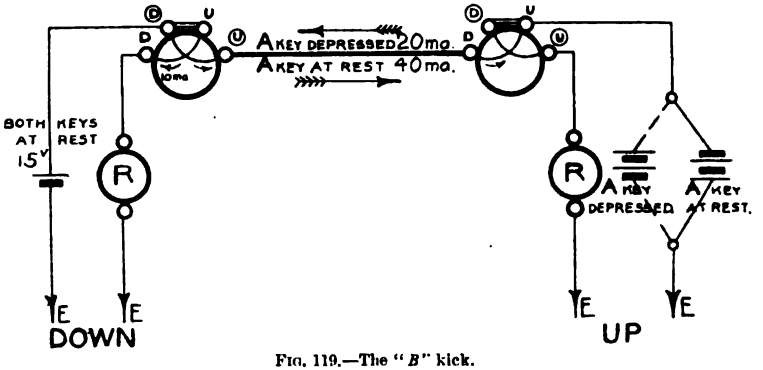

FIG. 119.—The "*B*" kick.

the effect under consideration. In other respects the diagram represents the actual connections suitably skeletonized. The two batteries shown at the up station represent the two ways in which the battery is connected under the two conditions described.

It has been shown that if the *A* key is depressed whilst the *B* key is sending a dash the latter signal is liable to be split. If the spring upon the non-polarized relay normally held the tongue to the spacing side, and the local battery and sounder were connected between *T* and *M* this result would be quite inevitable. In the Post Office quadruplex the spring upon the non-polarized relay normally holds the tongue to *M*, and a relaying sounder (see Figs. 77 and 78) is employed to close the local circuit of the reading sounder.

Relaying Sounder.

The terminals of the non-polarized relay (Fig. 120) are connected to a local battery and the coils of the relaying sounder. This local circuit is normally completed through the tongue of the relay, and the armature lever is therefore permanently held down. The reading sounder and local battery are connected between the lever and the top contact. The sounder is therefore only actuated when the lever of the uprighter rises and makes contact with its stop. This only occurs when the relay is actuated and its local circuit broken. The actuation of the relay therefore produces a mark upon the reading sounder the duration of which corresponds with the length of the signal. If the sounder and local were directly connected to *T* and *M* the marks received upon the relay would be "reversed," and the immediate object of the uprighter is to make the marks "straight."

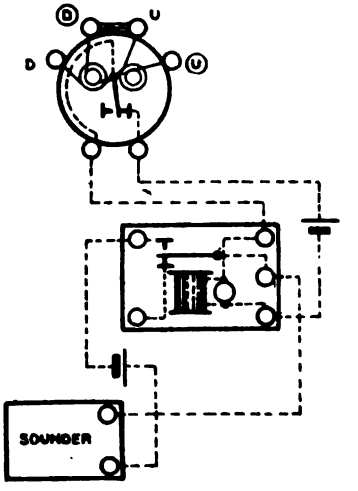

Fig. 120.—Relaying sounder "*B*" side.

It now remains to show how the interposition of the uprighter accomplishes its real object, viz. that of preventing the "*B* kick" from splitting the mark. Immediately the strength of the current becomes sufficiently great to overcome the pull of the spring upon the *B* relay the tongue breaks contact with *M*. This permits the lever of the uprighter to move upwards and start the mark upon the reading sounder. The mark commences therefore instantly the tongue breaks contact. If, whilst the tongue is resting on the left side, the distant *A* key is also depressed, the tongue is momentarily released from the left side, but before it can end the mark it has to travel across to, and make contact with, *M*. It is found that before this

can occur the current in the relay is re-established in the reverse direction, and that, therefore, the only effect of the *B* kick is to cause the tongue to momentarily recede from the left side, but not sufficiently to affect the signals. It will be obvious that if the sounder was joined directly between *T* and *M* and the spring normally held the tongue to the left, the smallest movement of the tongue would then break the mark upon the reading sounder.

The time taken for a current to rise to its maximum value is directly proportional to the product of the capacity and resistance of the circuit. This time is therefore greater in the case of long circuits and circuits having a considerable amount of underground than for short lines, and limits the length of the circuit over which quadruplex working is possible. For, when the time taken for the current to change in direction, and consequently for the relay to reverse its magnetism, becomes long enough to allow the tongue to touch *M* and so break the mark upon the sounder, quadruplex working is clearly precluded. The uprighting sounder device has therefore a definite limit beyond which it is ineffective. This is the case with the London-Birmingham underground, and quadruplex working cannot therefore be adopted.

The Condenser "*B* Side" Arrangement.

The arrangement depicted in Fig. 121 recently devized by A. W. Martin is now the standard practice upon the "*B* sides" of all quadruplex circuits. Whilst simplifying the adjustments, and so assuring greater reliability, it is also cheaper than the relaying sounder device.

The reading sounder is of the 900ω pattern, having coils of 1000ω, and a shunt of 9000ω resistance (see Chapter XV). The local battery has an E.M.F. of approximately 24 volts, and consists of 13 Bichromate cells. A 2 m.f. condenser is placed across the terminals of the sounder, and the platinum-tipped contact screw upon the non-polarized relay is changed over to the left side if the relay is of the older *B* pattern (both *S* and *M* contact points are provided in the *C* relay). The marks upon the sounder are thus made directly by the completion of the local circuit. The 100ω resistance coil and the ·5 m.f. condenser are placed across the

local contacts to avoid sparking. This will, however, be considered when the action of the 2 m.f. condenser has been dealt with. For the present it may be ignored.

In order to trace the action of the device, imagine that a dash is being received upon the *B* relay, and that the *A* key is depressed during its continuance. The 2 m.f. condenser is, during the mark, charged to the potential which exists across the terminals of the sounder. The depression of the *A* key causes the tongue to momentarily break the local circuit. Instantly this occurs the condenser discharges through the sounder, but, in addition, there is the current due to the self-induction of the sounder. Now the condenser acts as a short circuit across the sounder terminals whilst it is being discharged, and therefore the current due to the E.M.F. of self-inductance is correspondingly large. The condenser discharge current and that due to the self-inductance of the sounder are in such a direction as to continue the mark by preventing the magnetization of the sounder from falling to zero during the momentary break. Before this can happen the local circuit is re-established, and there is therefore no break in the received signal.

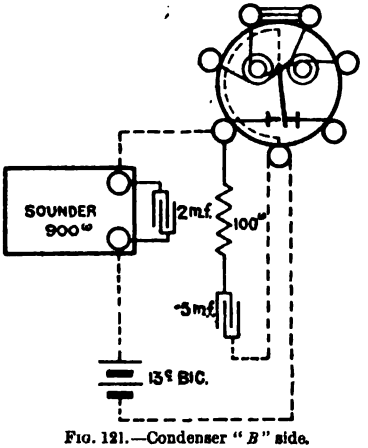

FIG. 121.—Condenser "*B*" side.

The ·5 m.f. condensers and 100Ω resistance coil are used to prevent sparking at the relay contacts upon completion of the local circuit. At the moment at which the circuit is made the 2 m.f. condenser is charged, and this would entail a heavy rush of current across the contact points if the alternative path provided by the smaller condenser were not available. It may be noted that when the local circuit is incomplete both condensers are charged with equal quantities of electricity, but that the difference of potential existing between the terminals of the 2 m.f.

condenser is 4·8 volts as against 19·2 volts across the smaller condenser. (See also arrangement described in Appendix C.)

A Key.

The *A* or reversing key is similar to a double current key but is not furnished with a "send and receive" switch. Its connections are identical with those of the corresponding four terminals of a double current key, and in actual construction there is also but little difference. The two outside lower contacts of the lever are mounted upon adjustable screws, as in the later patterns of double current key. This is done in order that the key may, in passing from the lower to the upper contact springs, momentarily short circuit the battery by making contact with the upper springs before breaking with the lower ones. The duration of the short circuit should, of course, be made as short as possible.

The *B* Key.

The *B* or increment key is a specialized form of single current key so arranged that the battery is never cut off from the *A* key. In order to accomplish this it is necessary that the lever of the key should make contact with the upper point before breaking with the lower. In the older form of key the lever played between two contact springs placed above and below the end of the lever. The upper contact point of the lever was adjustable so that the duration of the period of short circuit could be varied. A much later type of key is depicted in Fig. 122. Normally the right-hand spring rests upon a contact point to the left. The end of the key lever is provided with a contact point which, upon depression of the key, first makes contact with the spring, so short-circuiting the battery, and then raises the spring, so breaking the connection with the left stud. The lever is connected to the end of the *B* battery, the left contact to the tap wire and the spring to the *A* key.

If a single current key be employed as increment key in the way depicted in Fig. 118, it will be obvious that, during the time the lever is moving off the back contact on to the front one, the battery is momentarily disconnected from

the *A* key. In both the forms of key described above the *B* side of the battery is momentarily short circuited thus avoiding the disconnection of the *A* battery by the depression of the *B* key. In order to prevent excessive sparking a 100$^{\omega}$ resistance coil is connected between the end of the whole battery and the *B* key. Further, it will be obvious that the resistance of the battery should be the same whether the keys are at rest or depressed. Were this not so the distant balance would be disturbed when the positions of the keys were changed. It is consequently necessary to insert a resistance in the "tap" wire equal

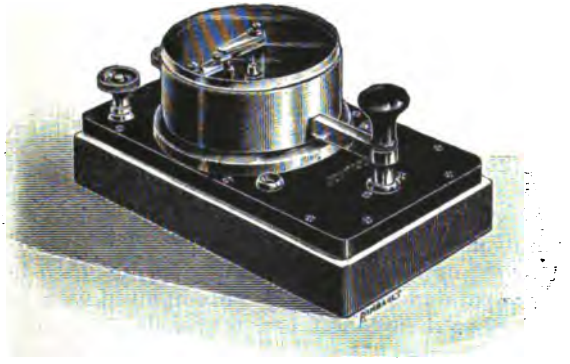

FIG. 122.—Increment key.

to the sum of the internal resistance of the *B* battery and 100$^{\omega}$ spark coil. The resistance of the battery circuit with the *B* key at rest is therefore equal to the internal resistance of the *A* battery plus the resistance coil equal to the internal resistance of the *B* battery and spark coil. With the *B* key down the resistance is that of the whole battery and the spark coil *i. e.* as before.

EARTHING ARRANGEMENTS.

The split wire is taken through a two way switch so that the batteries and keys may be cut out and a resistance equal to that of the battery circuit (internal resistance of the whole battery + spark coil) may be substituted. This provision facilitates the attainment of an accurate capacity balance.

Quadruplex Resistance Blocks.

The three resistance coils are officially designated "Quad-resistance blocks *A*, *B* and *C*." They differ from the ordinary resistances in shape and the size of the wire. The coils are fixed beneath a circular wooden case furnished with screw terminals. Since the *B* battery is short circuited through the spark (*A*) coil and the tap (*B*) coil the wire is of larger gauge to avoid excessive heating. The *B* and *C* coils are usually furnished with four terminals so that the resistances may be employed universally. The values which can be obtained are 50$^{\omega}$, 100$^{\omega}$, 150$^{\omega}$, 200$^{\omega}$ and 250$^{\omega}$.

Use of 6-Terminal Reversing Keys.

It has been found possible to use keys which do not short circuit the batteries, and in many new quadruplex circuits the 6-terminal reversing key is employed for both *A* and *B* sides. The key is fully described and illustrated in Chapter XVI, in connection with secondary cell working, and it will here suffice to say that it differs from the *A* key in having the upper and lower battery springs each brought out to a separate terminal. When employed with primary batteries as an *A* key these four terminals are connected so as to give the same connections as the *A* key already dealt with.

Upon the *B* side the same key is employed, but only one half of the key is actually used and therefore three of the terminals are left blank. Although the key does not short circuit the battery in passing from the lower to the upper springs, it will be obvious that the duration of the disconnection should be made as short as is consistent with immunity from short circuit.

Effects of Short Circuit and Disconnection in Intermediate Positions of the Keys.

The effect of the change from short circuit to disconnection in the intermediate position of the *A* key is of far less importance than would, at first sight, be supposed. The essential factor is the time which the *A* key takes to reverse the connections of the battery and, as the key is

finely adjusted, there is but little difference between the two arrangements. Whether the key disconnects or short circuits the "*B* kick" effect is necessarily experienced when the key is depressed in the middle of a mark from the *B* key.

In the case of the *B* key disconnection the effects are exclusively confined to the *A* relays. If both *A* keys are at rest the tendency of the momentary disconnection is to produce a false mark at the distant end due to the distant balance being upset. The reduction in the value of the line current necessary for this effect does not, however, occur with sufficient rapidity and the relay continues to space. With both keys down the distant relay might be expected to kick to spacing, but the same explanation also holds in this case. With one key down and one up the effect of the momentary disconnection is still less on account of the current in the line circuit being extremely small or even nil. Since the bias upon the relay is very small the tendency for the tongue to break contact is proportionately less. This is quite apart from the fact that the residual magnetism alone would probably suffice to prevent the mark from being interfered with.

It should be added that no change in the values or positions of the Quad-Resistance Blocks has been made as the result of the adoption of the 6-terminal reversing key for both *A* and *B* keys.

Connections.

The full connections of a quadruplex set as formerly arranged for an up station are shown in Fig. 123, and it is believed that but little difficulty will be found in memorizing them. The following points will, however, probably assist the reader :—

1. The sending current splits at the *B* relay.
2. The up station normally connects negative to the split.
3. Under normal conditions the relays space due to the combination of the batteries. (This gives the clue to the joining up of the line and compensation circuit.)

4. Left side of the A key is earth, and right goes to split of the relay (may be deduced from 3).
5. At the up office Z and C of the A key are respectively joined to Z of the battery and C to the centre of the B key (B key determines whether tap or end of battery goes to the A key).
6. For a down office reverse the battery wires on the A key and the line and compensation circuits on the galvanometer.

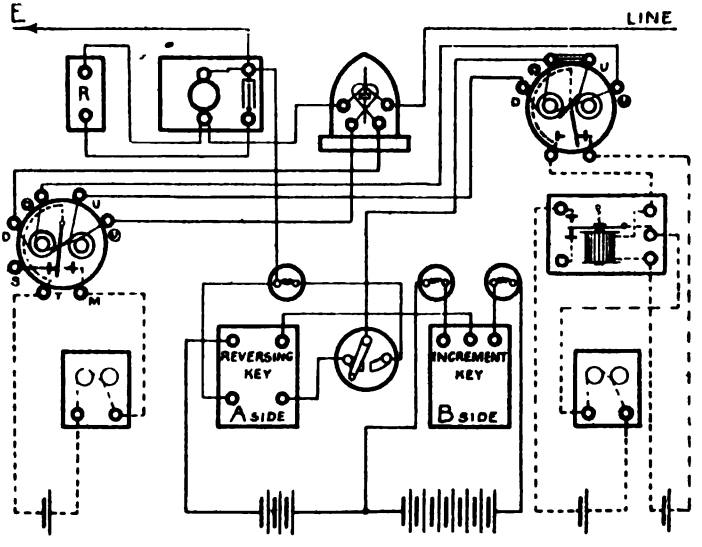

FIG. 123.—Connections of quadruplex up-station.

The local circuits call for no comment, and, if the function of the quad-resistance blocks is thoroughly understood, no other difficulty appears to present itself. The six statements given above are of some utility in verifying the accuracy of connections.

Upon existing quadruplex circuits the condenser B side device is being substituted for the uprighter, but this does not affect the general principles enunciated.

UNIVERSAL PRINCIPLE OF WORKING.

Very frequently the universal principle is adopted for

quadruplex working even where primary batteries are employed. The details of the arrangement are fully considered in Chapter XVI, and it will suffice to remark that the lamp resistances of Fig. 292 are replaced by metal-cased resistance coils and that the fuses are omitted.

Balancing.

The balancing of the circuit is accomplished in the same way as in duplex working, but there are the distinct advantages of the larger power and the earthing switch. Balancing should be effected with the full power (*i. e.* with the *B* key down), and the *A* key should be used in the same way as the double current key in duplex balancing. The distant earthing switch should be turned for capacity balancing, and the rules previously deduced (page 265) apply with equal truth to this operation.

Adjustment.

The adjustment of a quadruplex circuit is by no means a difficult matter, and the adjustments are reasonably permanent if carefully made. The whole of the trouble lies upon the *B* side, and it will be desirable to indicate a few obvious deductions from previous considerations. The *B* relay is worked by any current which attains a certain value greater than the *A* current. The best adjustment is therefore obtained when the *A* marks are just cleared off the *B* side. Assuming the values given in Fig. 119, it will be seen that if the *B* relay only marks when the effective current has attained 25 m.a. the effect of the *B* kick will be far larger than if it begins to work when the effective current has attained 12 m.a. If the relay works with the smaller current then the tongue is not released until the current has fallen from 30 to 12 m.a. instead of when it has fallen to 25 m.a., and it is again actuated when the current has risen to 12 m.a. instead of having to wait until it has increased by a further 13 m.a. The term effective current has been used to designate the difference between the values of the current in the two coils of the relays.

In clearing the marks off the *B* relay it is preferable to do this by removing the armatures further from the cores

instead of by increased tension upon the spring. This adjustment can be made by moving the contact screws. The tension upon the spring should not be greater than is essential for reliability of action. Again, the play of the tongue of the relay should not be reduced to the fineness of repeater adjustments. The tongue should have some distance to traverse before it can break a mark. This amount of play is definitely limited by the clear reception of the signals, and although, from the point of view of the "*B* kick," it is desirable to have considerable play, yet this cannot be accomplished at the expense of the received signals. The amount of play which will usually be found to be best is about equivalent to the thickness of a contact burnisher or that of the heavy lines in Fig. 118.

The uprighting sounder should be adjusted so as to accurately and sharply reproduce the received signals. The play of the tongue should be reduced to the smallest possible limits consistent with reliability. Here again the reduction in the sensitiveness should preferably be made by removing the armature further from the cores rather than by unduly tightening the spring. A reference to page 197 will reveal the fact that where great rapidity of action is desired the magnetic circuit must not approximate to a closed circuit, or, in other words, there must be distinct air-gaps. The cores of the uprighter are made very short in order that magnetization and demagnetization may be more rapid. The reason for making the play of the uprighter lever as small as possible should be quite obvious in the light of the explanations already given.

With the condenser device upon the *B* side the adjustment is quite an easy matter. The contact points may be approached as closely as is desired, but the minimum safe tension should be used upon the spring. The sensitiveness of the relay should be reduced by moving the armature away from the cores, rather than by excessive tension upon the adjusting spring.

The adjustment of the *A* relay and the sounders should call for no comment as the matter has been fully considered previously. The reader is particularly advised always to locate the point of defective regulation and to apply the remedy where the defect exists. A defect at one point may be partially rectified by defective regulation at a

second one, but this process inevitably leads to unreliable adjustments.

Decrement Working.

In order to dispense with the uprighter, and at the same time retain the advantages which its use entails, the decrement system of working is occasionally employed. This consists in arranging the *B* key to decrease the power when depressed, so that normally the full battery is connected to the *A* key. With all the keys at rest the tongues of the *B* relays are held away from their *M* contacts. The depression of the *B* key reduces the current and permits the tongue to make contact with *M*, and as the sounder and local battery are connected directly to *T* and *M* the sounder is actuated. Over short distances this system is quite as satisfactory as the increment system, and it has the advantage of reducing the number of possible adjustments by dispensing with the uprighter. Upon the other hand the full power is normally connected up, and therefore the energy required is certainly greater than in the increment system. Moreover it normally leaves the full power connected to the line, and where gutta-percha insulated underground wires are concerned this is undesirable. For very long lines it is not as satisfactory as the increment system and there are many lines now working increment which could not be worked at all on the decrement plan.

In order to convert an increment into a decrement quadruplex the wires upon the two outer terminals of the increment key are reversed, and the local circuit of the *B* relay is directly connected to the reading sounder and its local battery. The platinum-tipped contact screw of the *B* relay is of course moved to the left side.

Use of Bridging Coil.

In new quadruplex circuits a bridging coil having a resistance of 100 ohms is included in the compensation circuit, in order to balance the self-inductance of the distant receiving apparatus. The coil has an iron case thus giving a closed magnetic circuit. Its self-inductance is equal to that of one coil of each relay and one coil of the galvanometer. Without this device a quadruplex circuit cannot be worked over a short line (see page 244).

Other Quadruplex Systems.

The general principles of the Post Office system of quadruplex working have now been stated, but it will be obvious that the same object may be accomplished in different ways. The Bridge system of working could readily be adopted, but it must be confessed that although such an arrangement has been proposed it has rarely if ever been put into practice. Either this or the differential system may be worked by combination or by opposition, the former being the method adopted by the Post Office.

The quadruplex systems of America differ from our own chiefly in the arrangement of the non-polarized relay. In every case the keys are employed to complete local circuits which work transmitters similar to those described in Chapter XVII. In many cases a third coil is wound upon the *B* relay, and so arranged as to accelerate the reversal of the magnetism of the relay.

Faults.

In dealing with quadruplex as with faults in other types of apparatus it cannot be too strongly urged that it should always first be ascertained whether the defect is at the home end or not. It is advisable to always start with the assumption that an apparatus fault exists in the home apparatus.

It is most important that the ratio of the *A* and *B* currents shall be as one is to three. If the ratio is less than this amount satisfactory and reliable working is difficult. Again the powers employed at the two ends should be very approximately equal, but differences in this respect occur only by accident.

If the *B* key has no effect upon the strength of the current received at the distant end it is obvious that the *B* battery is short circuited. If disconnected the *A* marks received at the distant end would be destroyed and the balance upset whenever the *B* key was in the faulty position.

A fault in the *A* key causing it to send out only one current would break up the distant *B* marks, but would not affect anything else, as it is quite possible that the

distant *A* side would be re-regulated to work with but one current without the cause for the alteration being discovered. At the office where the defect exists the signals would be received perfectly upon both the *A* and *B* sides. Such faults as this, and the one preceding it, should be discovered when observing the ratios of the received currents upon the differential galvanometer.

A disconnection in the line or compensation coils of the relays or galvanometer should readily be found, and everything which has been said in regard to duplex working applies with equal force to the present case.

A contact between the two coils of the relays or galvanometer is evidenced by impossibility of balancing. If in the *B* relay, it will be possible to balance in the ordinary way, but the *B* relay will not then be differential. If the contact is near the *D* and *U*-circle ends of the relay it will be equivalent to cutting it out altogether. A contact at any other point will have similar results, viz. that when the circuit is balanced by the galvanometer the keys still affect the apparatus.

A short circuit in the coils of any of the relays or galvanometer produce a like result, but here it is possible to clear the marks on both *A* and *B* relays by disregarding the galvanometer and balancing by observing the effect upon the working signals. If either relay has a short circuit then the faulty relay is affected by the keys when both the galvanometer and the perfect relay are balanced.

Faults in the local circuits are self-evident, and the adjustments have already been dealt with.

In observing the received currents both the distant keys should be proved in each position and the distant station should similarly observe the home apparatus. In the majority of cases the trouble lies in the adjustment of the *B* side, and faults such as those described are comparatively rare. Possibly this accounts for the difficulty sometimes experienced in locating them.

Current Required and Type of Battery Used.

Bichromate batteries are invariably used upon all quadruplex circuits, and the current required is from 10 to 15 m.a. upon the *A* side and from 30 to 45 for full power.

The ratio of at least three to one should always be maintained. The two parts of the battery are often termed the *A* and *B* batteries, but it has been seen that the depression of the *B* key introduces the whole power, *i.e.* both *A* and *B* batteries.

The two sounder locals are each 3-cell Bichromates, and the relaying sounder the same (formerly two 5-cell Large Daniells in parallel). With the condenser *B* side the local battery is a 13-cell Bichromate.

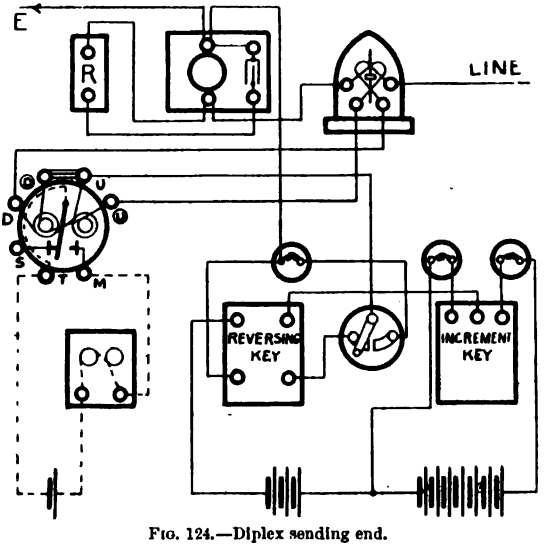

FIG. 124.—Diplex sending end.

THE DIPLEX.

The diplex consists of a quadruplex at one end of which the *B* key and the major portion of battery power ordinarily required is omitted, and at the other the corresponding *B* relay is not needed. This arrangement provides for the simultaneous transmission of two messages in one direction and one in the opposite direction. At cricket grounds and other places where special arrangements are frequently made it often happens that practically the whole of the work consists in the transmission of messages *from*

the special office. Where this is the case there is no advantage in providing two receiving paths at the special office, but one such path is essential for corrections and acknowledgments of the messages transmitted.

The connections of the two ends of a diplex circuit are shown in Figs. 124 and 125, and call for little comment.

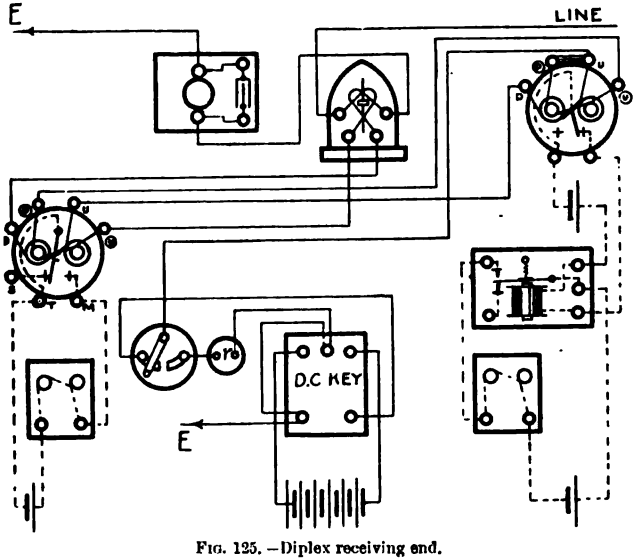

FIG. 125.—Diplex receiving end.

A double current key is often used at the up office instead of a reversing key, and the send and receive switch may be arranged so as to join up the battery coils when at receive. The advantage gained in omitting the apparatus not actually needed lies in the greater simplicity and the saving of the extra battery power which may have to be specially provided where secondary cell working is not in vogue.

WHEATSTONE UPON THE *A* SIDE.

A Wheatstone transmitter may be added and a receiver substituted for the relay. In order to add a transmitter the wires upon *Z* and *C* of the *A* key must be

removed and connected to *Z* and *C* of the transmitter. *MKZ* and *MKC* are then joined to *Z* and *C* of the key. The wire on the left of the two-way switch is taken to *D* of the transmitter, and *K* is connected to the lower right terminal of the reversing key. Transmitter *U* is then earthed and the addition of the transmitter is completed. The substitution of the receiver for the *A* relay is quite obvious.

It is stated that 200 words per minute in either direction with the *B* key working can be obtained from a quadruplex with Wheatstone on the *A* side, but it should be realized that the adjustments to obtain such a result require the very greatest care and attention.

Frequently the decrement system is employed, and the *B* side is stopped while Wheatstone working is in progress, so providing full power for the process.

The latest arrangement of the increment quadruplex, described in Chapter XVI, provides for Wheatstone working on the *A* side.

CHAPTER IX

THE WHEATSTONE AUTOMATIC SYSTEM.

General.

THE generic term "automatic system" is usually employed to denote all the systems in which the signals are transmitted by mechanical means as opposed to those in which the signals are sent by a manually operated key. The speed at which most circuits can be worked by a machine transmitter greatly transcends the speed at which even the most highly expert Telegraphist can operate a key. Moreover, the speed is constantly maintained and the marks are more accurately formed than would be possible with a key worked by hand.

The Wheatstone system is employed by the Post Office, and although many other systems have been proposed, few have been practically employed. Certainly none of them are of sufficient present importance to justify their inclusion in the present volume.

The Wheatstone apparatus comprises three separate and distinct parts. Firstly, the perforator, which is employed to prepare the tape, or "slip" as it is termed, which controls the signals sent out. Secondly, the transmitter, which serves to send out signals in accordance with the perforations of the slip. Thirdly, the receiver which is a very sensitive form of polarized direct writer.

In addition to the above essentially Wheatstone instruments a galvanometer, sounder, line and local batteries are, of course, required.

The Perforator.

The perforator (Fig. 126), which is purely mechanical in its action, consists of five steel punches operated in suitable

combinations by the three keys, the slip being automatically moved forward to the required extent immediately the key is released. The slip is from ·46 to ·48 inch wide, from 4 to 4½ mils in thickness, and is treated with olive oil in order to ensure cleanly perforated holes.

Operation of the Punches.

The five punches occupy the relative positions shown in

Fig. 126.—Perforator.

Fig. 127, and have been marked 1 to 5. Punches 2 and 4 are of smaller size than the other three and serve to form the central guiding holes. The middle key operates punch 2 only. This punch is attached to a small plate, and the extension of the middle key, upon depression, strikes the pin *b*, so forcing the punch through the slip thus perforating a centre hole as shown under R_1 (Fig. 128). The left or dot key depresses punches 1, 2, and 3, and perforates as at R_2. The right key operates punch 1 by means

of the extension plate and pin *a*, 4 and 5 directly, whilst 2 is operated from 4. Punch 2 can be operated independently of 4, but when 4 is struck 2 moves with it. The perforations resulting from depression of the dash key are shown at R_3.

Paper-Feeding Device.

The device for feeding the paper forward either one or two spaces as required may be seen in Fig. 129. The lever *K*, which has its axis upon the right, fits into notches

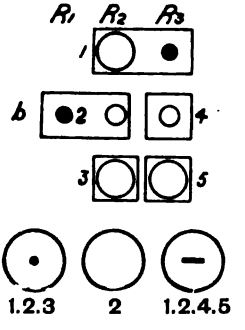

Fig. 127.—Arrangement of punches.

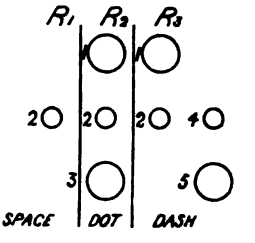

Fig. 128.—Perforations for space, dot and dash.

cut in the underside of the levers R_1, R_2 and R_3, and is articulated with the crank *P* at *e*. Near the end of *P* is fixed a double-toothed pawl *E* engaging with the star wheel *S*. The drum-shaped wheel *W* is carried upon a light spring and holds the pawl in its normal position. The levers *K* and *P* are normally held in the positions shown in the figure by the action of the powerful spring *B*, the tension upon which may be adjusted by the screws *C* and *D*.

When the centre key is depressed punch 2, actuated by R_1, passes through the slip and the levers *P* and *K* move forward (downward in the figure), thus carrying the click *E* to the left.

Immediately the key is released the spring *B* returns the levers to their normal positions and the click engages a

tooth of the star wheel, thus moving it forward and bringing the paper into position for the next perforation. A similar result occurs when the left key is depressed, and the paper is again moved forward by the requisite amount. The distance to which the front end of the lever P can be moved to the left is limited by the stop L, but when the right key is depressed this stop is raised and P moves further to the left to M, with the result that the star wheel is moved round two teeth, as is obviously necessary. The lever L

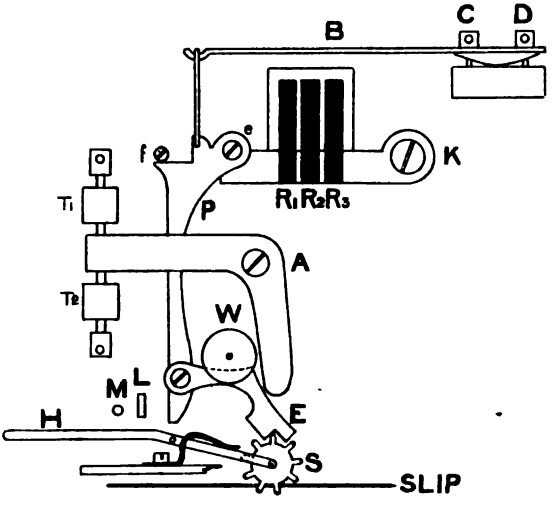

FIG. 129.—Part of perforator mechanism.

curves over the pawl and is pivoted upon the right. It is directly connected beyond the pivot to the lower side of the "dash" lever beneath the perforator base.

A consideration of Fig. 130, showing a vertical section through punches 1, 2 and 3, taken in conjunction with Figs. 127 and 128, will render the arrangement of the punches quite evident. The two spiral springs serve to return the punches (shown depressed) to their normal positions immediately the key is released. The ends of R_1, R_2 and R_3 are of sufficient depth to operate the three rows of punches.

The star wheel *S* is carried by the lever *H* which serves to withdraw it when inserting the slip between the plates. The centre key is struck and the slip pulled gently forward until the star wheel engages with the centre holes.

PUNCHES.

The solid punches formerly employed required frequent sharpening in consequence of their edges wearing away by the action of the oiled paper perforated. This was principally due to the fact that at each blow of the punch, a film of dried oil was deposited by the paper upon the surface of the punch which soon built up into convex form, the consequence being that the paper was bent over the punch before being perforated, and quickly wore away the cutting edge

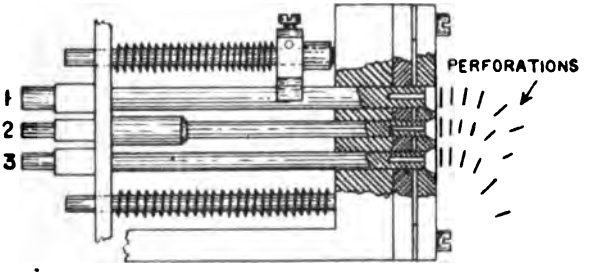

FIG. 130.—Perforator punches.

of the punch. Moreover, the perforations being bent by this process, were sluggish in leaving the plates.

The new form of punch designed by J. W. Willmot has a hollow recess at its end, and therefore has no centre on which a deposit of oil can take place. As the annular surface of the punch remains flat a clean perforation is always made. It has a further advantage, *i.e.* that in coming into contact with the paper to be perforated a small amount of air is compressed in the recesses of the punches, which, after the perforation has been made, tends to blow away the punched-out portions of the paper, and also to prevent any oil or foreign matter accumulating in the recesses of the punches. The holes in the front plate through which the perforations are expelled have been

chamfered, thus facilitating that process. When the punches require sharpening, the hollow or recessed punches are more easily ground, and a flatter surface obtained than is possible with solid punches, because firstly, having no centre there is less metal to grind away, and secondly, for the same reason they lie flatter upon the cutting surface of the oil-stone used for sharpening them.

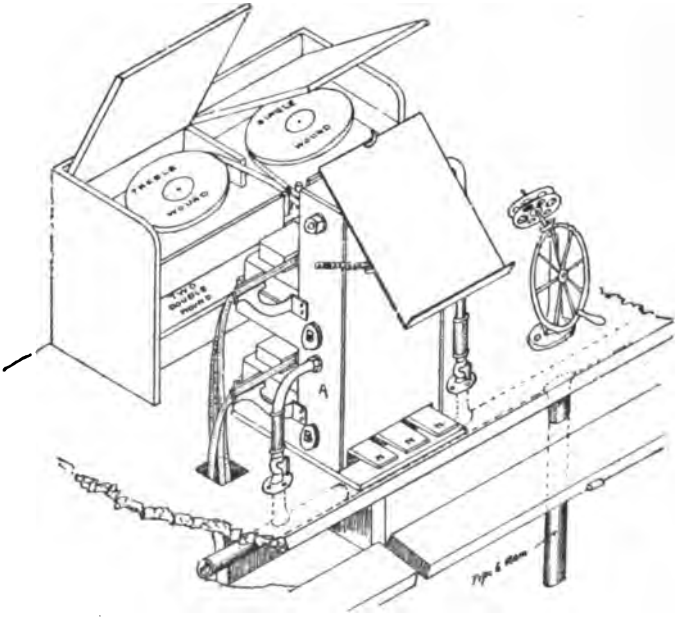

FIG. 131.—Appearance of a pneumatic perforator.

AUXILIARY APPLIANCES.

The perforator is mounted upon a wooden stand provided with a drawer for receiving the perforations. Behind this is placed the box containing the roll of slip, and the second lid is raised to form a stand for the message or manuscript to be punched.

The keys of the perforator are operated with iron punching handles, the ends of which are recessed to receive the

striking cushions of solid rubber. Two slips may be simultaneously perforated, and therefore double wound rolls of paper are also provided.

Perforator Adjustment.

The adjustment of the perforator is a matter of considerable importance, and the bent lever *A*, with its adjust-

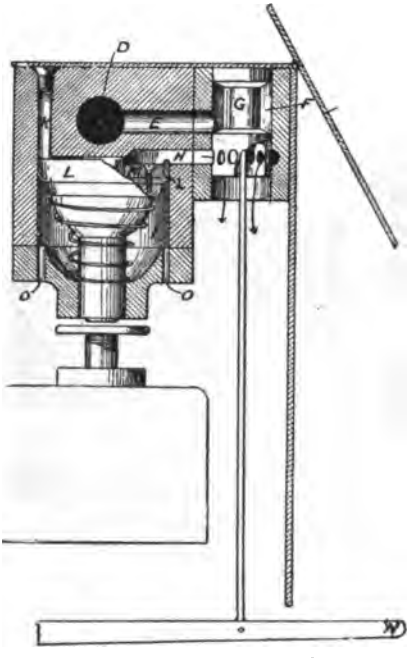

Fig. 132.—Pneumatic perforator valve and piston.

screws T_1 and T_2 is provided for this purpose. The lower extremity limits the distance at which the click engages the star wheel, and therefore the distance through which it is turned. The standard is 121 central perforations per foot, the distance being measured from the centre of the first to the centre of the 121st perforation. If the word "telegraphs" is punched three times with the double spaces

between the words the requisite number (121) is obtained between the first and last holes.

Pneumatic Perforators.

In certain very large offices pneumatic perforators are employed. In this way from one to eight slips can be simultaneously prepared. Four rolls of paper, one treble, one single and two double wound are provided, as indicated in Fig. 131. The two perforators are actuated by the three

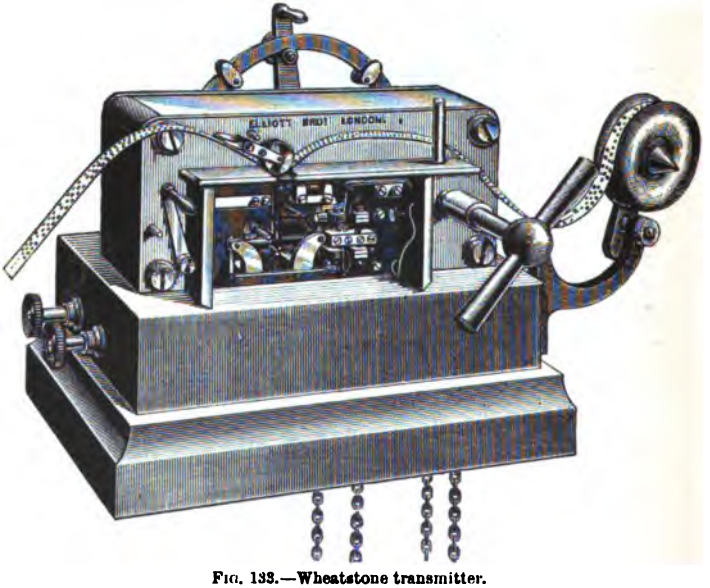

Fig. 133.—Wheatstone transmitter.

keys which are to be seen in the forefront of the figure. These keys operate valves (Fig. 132) which admit the compressed air, obtained from the pneumatic tube plant, into the piston chambers. Each perforator has an independent supply of air, and either or both may be worked at will. The sizes of the pistons are of course dimensioned so that the dot and dash keys which operate respectively three and four punches receive a heavier blow than the space key which operates but one punch.

TRANSMITTER.

The Divided Lever.

The transmitter (Fig. 133) consists of a special form of double current key, the movements of which are determined by the positions of the larger holes in the perforated slip. This key consists of a divided lever playing between four

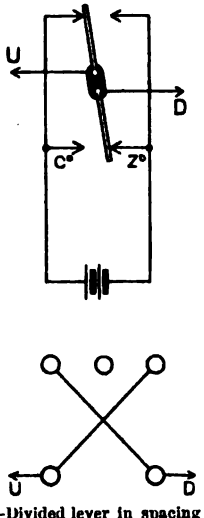

Fig. 134.—Divided lever in spacing position, and the corresponding connections of a double current key.

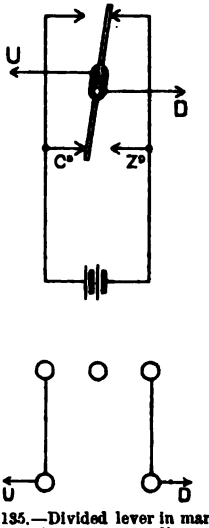

Fig. 135.—Divided lever in marking position, and the corresponding connections of a double current key.

contact points, and may conventionally be represented as in Figs. 134 and 135. The upper and lower halves of the lever are mechanically connected but are electrically separate, *i. e.* insulated from each other. The two positions of the lever are shown side by side with the corresponding positions of a double current key below them. The upper half of the lever is connected to the up line and the lower half the down line, and the battery contacts have been marked to show the connections which result when the lever rests against them. It will be seen that the deflection of the lever (top) to the left makes the same connections as a double

current key at rest but with its switch to send. The actual arrangement of the divided lever is shown upon the right in Fig. 136. The battery contacts correspond strictly with the positions shown in the previous figure, and the upper and lower halves of the lever are distinctively marked. The upper part terminating under J is merely mechanical in function.

It now remains to explain the mechanism by which the perforated slip controls the position of the divided lever.

Motive Power.

The mechanical power required to drive the transmitter mechanism is furnished by the gradual descent of a heavy weight acting through a train of wheels. A key for periodically raising the weight and a governor operated through a variable speed gear form part of the arrangement. The descent of the weight causes the rocking beam to move up and down at a speed which conforms with the rate at which the star wheel moves the perforated slip through the instrument. These two allied movements are made by suitable gearing. The rocking beam is furnished with two pins P and P_1 (Fig. 136) which project horizontally and oscillate with it. The movement of the beam is effected by a horizontally projecting pin placed near the edge of the revolving wheel and connected by a lever to one end of the rocking beam. The revolution of this driving wheel causes the beam to rock up and down upon its central pivot.

Arrangement of the Reciprocating Rods and Divided Lever.

The two pivoted cranks A and A_1 are held against the lower side of P and P_1 by the two spiral springs connected at right angles to the lower extensions of A and A_1. Rising from the ends of the two cranks are the pivoted rods S and M. The rod S is directly in front of M, but their positions have been modified in the figure in order that both might be distinctly shown. The play of the rods in a direction to the right is limited by two adjustable screws against which they are normally held by the two spiral springs fixed to them and to the pin on the right. The rods pass through two slots in the brass case (shown in Fig. 133) of sufficient

width to readily admit them, but without permitting any considerable movement in a direction transverse to the motion of the slip past them. Between the rods is placed the star wheel, the projections of which pass through the central holes of the perforated slip, so guiding and propelling it. Above the star wheel is placed a wheel rather broader than the slip and with grooves which engage the projections of the star wheel as they pass through the slip. This wheel is furnished with a handle, so that the slip may readily be removed without having to wait until the whole length has passed through the transmitter.

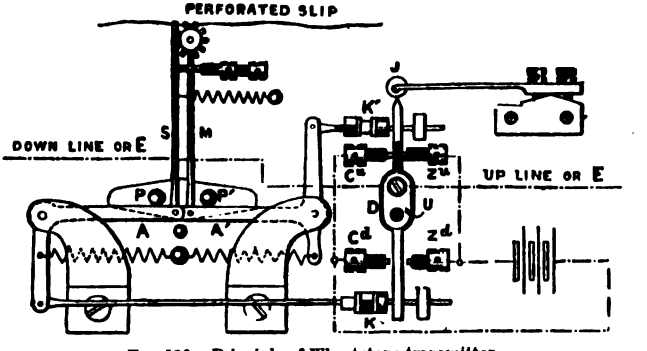

FIG. 136.—Principle of Wheatstone transmitter.

With no slip in the transmitter the rods S and M follow the motions of the rocking beam, and so alternately rise and fall with it. The lower end of the left crank moves to the right when the rod S rises, and this pushes the divided lever over to the right by means of the rod and boss K. The rising of the back rod M similarly causes K_1 to move the divided lever to the right. Examining the last two sentences with the aid of Figs. 134 and 135 will show that a spacing current is sent out when the front rod S rises, whilst a marking current results from the rising of M. The effect of running the transmitter without slip is to send out an unbroken series of reversals which register dots upon the distant polarized receiving instrument.

If, after the marking rod has risen, the spacing rod is stopped at the level of the paper, the marking current will

be continued until the spacing rod is able to rise. The marking rod in rising moves the divided lever over to the right (upper part to the right, lower to the left), and it is held firmly against the contacts by the jockey wheel *J*. The lever never permanently occupies the central position shown in Fig. 136, but this method of drawing shows clearly the correct relative positions of the jockey wheel and the upper extension of the divided lever. This extension is mechanical and is electrically separate from the upper half (up line terminal) of the lever. It will be seen that immediately the lever moves to either side of the centre of the jockey wheel the spring which carries the wheel insures that the contacts shall be firmly made and maintained.

Action of Transmitter in Signalling a Word.

A sketch of the perforated slip required to transmit the word "and" is shown in Fig. 137. The upper holes pass the rod *M*, and the lower ones pass *S*. When in the transmitter the lower holes are to the front of the transmitter, and the slip moves past the rods from right to left. The exact process by which the punched holes in the slip control the positions of the lever may now be very readily traced. Let the perforated slip depicted in Fig. 137 be passed through the transmitter, and let it be assumed that prior to this the *S* rod last rose above the level of the paper. This being so, the lever was pushed over to the left (lower portion to the right), and is held there by the jockey wheel and spring. The central holes of the slip engage the star wheel, and the slip is drawn forward. The marking rod rises with the upward movement of P^1 (Fig. 136), but meets the full paper which prevents it rising sufficiently to cause K^1 to touch and push over the divided lever. The spacing current therefore continues. The spacing rod next rises when *P* moves upwards, but, meeting the full paper, it does not cause *K* to touch the lever. The rod *M* on rising again is still met by the paper, and is therefore unable to stop the spacing current which still continues. The spacing rod next rises, but is met by the paper. The first holes are now opposite the rods, and when the marking rod rises it passes through the hole and reverses the position of the divided lever, thus sending out a marking current. The

spacing rod upon rising passes through the hole opposite that through which the marking rod has just passed. This returns the lever to the spacing side, and ends the mark by restoring the spacing current. Where the two rods successively pass through two holes directly opposite each other the shortest marking current, a dot, is transmitted. The marking rod now rises through the hole opposite 5, and a marking current again results. The spacing rod, however, is met by the full paper, and is therefore unable to reverse the lever, with the result that the jockey wheel still holds the lever to the marking side. The marking rod next rises opposite 6, but meeting the full paper leaves matters *in statu quo*. The spacing rod now meets a hole, and upon rising through it, withdraws the mark by reversing

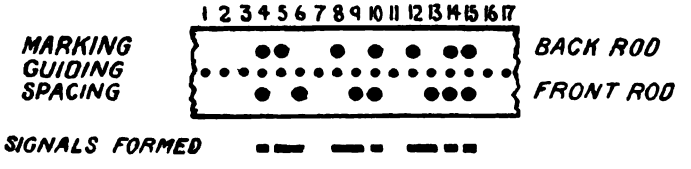

FIG. 137.—Perforated slip and corresponding received marks.

the lever. At 7 the marking rod is unable to fully rise, and the space continues until it again rises at 8. The mark then commenced is not ended until the spacing rod has risen for the second time when it passes through the hole and ends the dash at 9. At 10 a dot is transmitted, and the spacing current again continues until 12 is reached, when the dash in "d" is transmitted, followed by the two dots. The last current is of course spacing.

In commencing the detailed explanation of the transmission of the word "and" it was assumed for convenience that the divided lever was on the spacing side. This assumption is not warranted, since it may readily happen that in putting in the slip *M* was the last rod to rise above the level of the paper. The effect would be that a continuous mark would be registered until the spacing rod rose at 4. In perforating a slip for transmission a few A's are usually punched before the actual message, in order that the first signal of the message may be clearly received and may not be merged into a continuous mark.

Summary of Action of Transmitter.

The results of the previous investigations into the action of the transmitter may now be summarized—

1. The back rod and back holes control the marking, and the front rod and front holes the spacing currents.

2. The last rod to rise above the level of the paper produces an effect (spacing or marking) which is continued until the other rod rises above the level of the paper.

Magnetic Bias Transmitter.

In the latest pattern of transmitter the jockey wheel has been replaced by a magnetic bias. The arrangement is depicted in Fig. 138, where it will be seen that the upper part of the lever plays between the polepieces of a powerful horseshoe magnet. The device is so entirely similar in action to a relay which has been adjusted to neutrality that detailed description is scarcely necessary. Suffice it to say that when deflected to either side the extension of the divided lever is nearer to the pole-piece against which it deflects, and that magnetic attraction serves to maintain the contacts made by the movement of the lever. The advantages gained are (1) the entire elimination of the heavy downward pressure due to the use of the jockey wheel and spring, (2) the lever is held over more firmly, (3) it requires a smaller relative movement between the magnet and the divided lever than was necessary with the jockey wheel, and (4) it requires less power to drive.

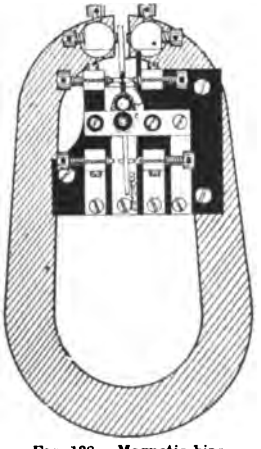

Fig. 138.—Magnetic bias transmitter.

Whilst effecting this change an opportunity was taken to substitute pivoted crossheads for the holes and pins of the horizontal levers, and also to make their adjustments more easily accessible. These improvements, due to J. W. Willmot, have had a marked effect in two directions; firstly, greater permanency of adjustments; and secondly,

far less wear and tear of the moving parts. The former is a matter of the utmost importance for the reason that the adjustment of a transmitter is at the best a lengthy and tedious operation, and when traffic is being delayed by such a fault it is quite hopeless to attempt to remedy it on the spot. In such cases a new transmitter should be substituted at once.

Transmitter Bias.

The four battery contact screws require most careful and accurate adjustment in order that the currents sent out by the transmitter may be of exactly equal duration. The positions of K and K_1 (Fig. 136) are, for the same reason, of equal importance. When once made re-regulation is not required for some time, but it is inevitable that sooner or later the relative positions of the moving parts will slightly alter. The result in a pronounced case is that the transmitter sends out a current in one direction only when run without slip. In less pronounced cases the defect is termed a marking or spacing bias according to whether the marking or spacing current is of longer duration than the other. If the currents are, as they should be, of exactly equal duration and value the needle of the galvanometer will oscillate to an equal extent upon either side of zero. If the galvanometer is permanently deflected it is evidence that a bias exists, or in other words that the marking and spacing currents are of unequal length. Therefore, to prove a transmitter it should be run very slowly without slip, and the value of the deflections upon the galvanometer in both directions should be quite equal. The speed should then be increased, when the galvanometer should stand at zero, or rather should oscillate to an extremely small extent about zero.

Arrangement for Regulating the Speed of the Transmitter.

It is essential that the speed of the transmitter should be capable of wide variation in order that the same instrument may be used upon all Wheatstone circuits, and also to meet the case where a reduction in speed is necessitated by slight defects upon the circuit. This is effected by the

governor and the variable speed gear shown in Fig. 139. The smaller german silver disc V serves to transmit the motion of the steel driving disc G to the steel fan

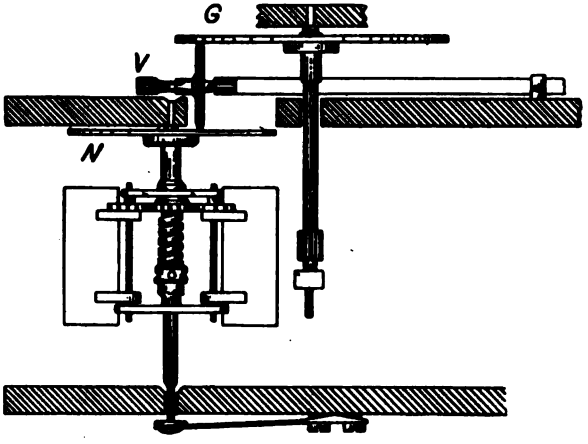

FIG. 139.—Arrangement of speed gear and fans—Lever at "Slow."

disc N. Now the position of V between G and N may be altered by means of the speed lever. In Fig. 139 the

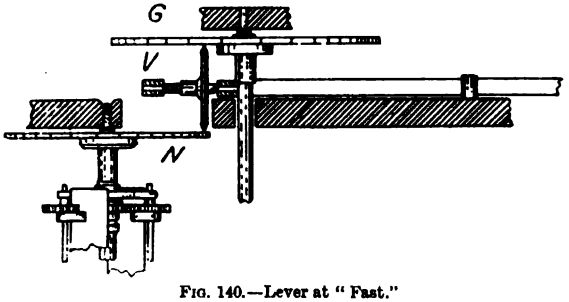

FIG. 140.—Lever at "Fast."

fan disc N revolves much faster than the driving disc, and therefore a comparatively slow motion of G produces a relatively fast motion of N. When the disc V is moved to the position shown in Fig. 140, the conditions are

reversed and a fast motion of the driving disc produces a relatively slow motion of the fan disc.

The two fans are mounted upon toothed wheels engaging with the wheel upon the axle of the fan. Normally the fans are held in the position shown in Fig. 141 by the action of the spring which is clearly visible in Figs. 139 and 140. Immediately the fan disc begins to move the fans fly outwards (see Fig. 139) by centrifugal force, and offer a resistance to passage through the air which becomes greater and greater as the area of the circle described by the outer edge of the fans increases. It will therefore be seen that when the connecting disc *V* is in the position shown in Fig. 140, the speed of the transmitter is least on account of the energy taken to drive the fan. In the previous figure the conditions are reversed, and the energy taken up by the fan is correspondingly less since a fast motion of *G* produces a relatively slow motion of *N*.

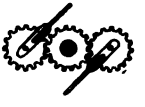

FIG. 141.—Fans closed.

Since the friction between the three discs is relied upon to transmit the motion of the driving system to the fan governor it is essential that the discs should be firmly pressed together, that the surfaces which are brought into contact should be perfectly smooth, and, lastly, that the discs should be absolutely clean. The spring *S* acting on the axle of the fan holds the fan disc in firm contact with the movable disc. A jewelled bearing is employed, as the wear upon the pivot would otherwise be very great.

ACTION OF FAN IN MAINTAINING UNIFORMITY OF SPEED.

The fan governor also performs another important function in eliminating all minor fluctuations of speed. If, whilst the instrument is running, there suddenly occurs a tendency towards reduced speed the fans move inwards a little, thus taking less energy to drive them, and so reducing the effect. In similar fashion the governor opposes any sudden increase of speed.

STOPPING AND STARTING LEVER.

A lever is provided to stop and start the transmitter. This lever when in its left-hand position (transmitter

stopped) engages with a projection upon the axle of the fans. When turned to the right the fan axle is released and the instrument at once starts. In addition, the lever actuates a switch placed upon the under-side of the instrument. This switch is described and explained upon page 320, under the heading of "transmitter switch."

"Bolting" of Transmitter.

If, by any chance, a little grease or oil should get on the discs or should the spring become weak the transmitter will "bolt." The whole of the mechanism which is driven by the weight is released from the control of the governor, the speed becomes abnormally great, and the weight rapidly descends. This descent is in fact so rapid that injury would result if the foot were caught by the falling weight, and therefore an iron guard is always placed round the weight in such a way as to prevent the feet from being placed beneath the weight.

Speed of Slip.

The speed at which the slip passes through the transmitter should range from not *more* than 7 to not *less* than 80 feet (400 words) per minute. The speed of working may be obtained by dividing 3000 by the time in seconds occupied in passing 10 feet of perforated slip through the instrument. As the base of the receiver is exactly 12 inches long it may be used as a measure.

THE RECEIVER.

The receiver is a polarized direct writer of somewhat special construction. Its electrical and magnetic parts are almost identical with those of the standard relay. Between its two electromagnets are placed two soft iron armatures rendered magnetic by induction from a powerful horseshoe magnet placed behind them. There is, however, the difference that the spacing screw moves the electromagnets bodily to right or left according to the direction in which the screw is turned. In a relay the contact points are mounted upon a movable platform, whilst in the receiver they are fixed.

Since there is no necessity to limit the space taken up by this magnet it is not curved round the coils. The upper end of the axle carrying the armatures bears an arm through which passes the revolving ink wheel axle (Fig. 142). The movements of the armatures produce a lateral movement of the ink wheel, so bringing it into contact with the slip and thus making a mark. The standard breadth of the marks is 16 mils.

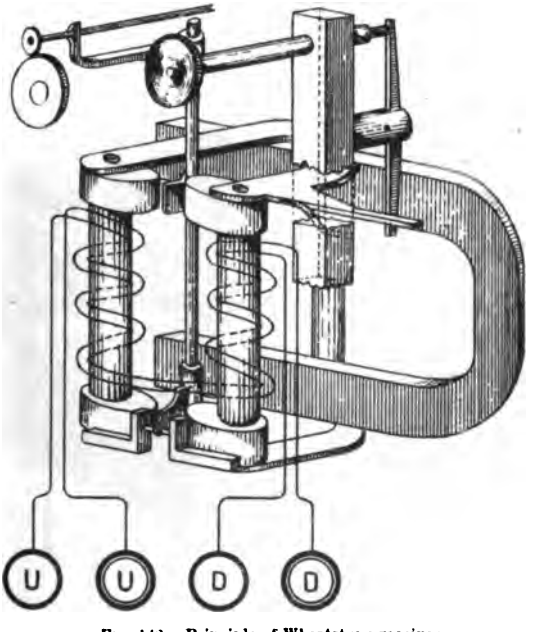

FIG. 142.—Principle of Wheatstone receiver.

INKING ARRANGEMENTS.

The armatures normally rest upon the right side, and a current in the direction *U* to *D* causes them to be deflected to the left. The small inking wheel (Fig. 142) revolves in a direction opposite to that in which the slip ($3\frac{1}{2}$ mils thick) is carried past it, and it is kept inked by the larger feeding wheel which dips into the ink well. This wheel

revolves in the opposite direction to the inking wheel, and is normally all but touching it. The object of the device is to prevent large quantities of ink being thrown on to the paper when the speed is varied, and the use of the intermediary wheel insures that the inking wheel shall always be sufficiently inked, but at the highest speed shall not be inked to such an extent as to cause the marks to be indistinct. In fact so well does the arrangement fulfil its function that there is no practical difference in the marks between slow and full speed.

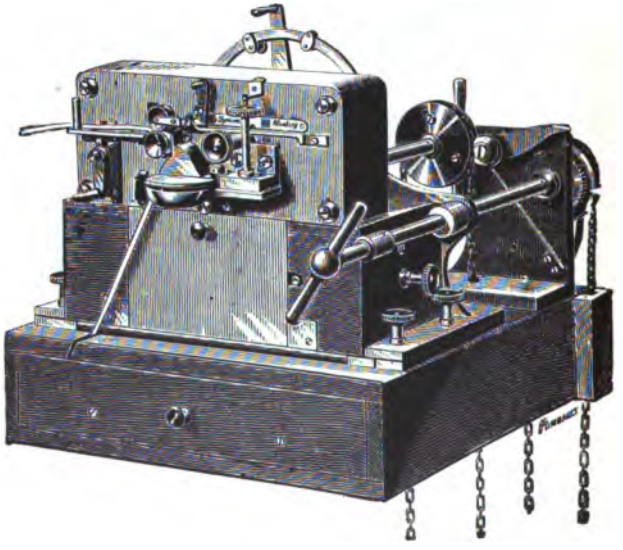

FIG. 143.—View of a Wheatstone receiver.

MOTIVE POWER.

As in the case of the transmitter the power is supplied by a weight geared to a train of wheels. The speed is adjustable by means of the lever at the back which alters the position of the german silver driving disc upon the fan disc in a similar manner to that described in the case of the transmitter. The speed of the star wheel in a Wheatstone transmitter is much higher than that of the paper roller in the receiver, and therefore the variable speed gear

in the latter case is of a somewhat simpler form. The german silver disc is carried upon an axle which is directly geared to the driving axle by means of toothed wheels, and there is thus only one connection produced by friction. The governor used to regulate the speed and the starting and stopping device are also similar to those used in the transmitter.

The descent of the weight causes the slip roller and the inking and feeding discs to revolve. Above the slip roller is placed a second roller which may be raised by moving the small front lever at the top of the instrument to the right. This facilitates the removal of the paper dust which accumulates round these parts of the receiver. The general appearance of a Wheatstone receiver is shown in Fig. 143.

Double Slip Drawer and Bell.

Receivers are frequently furnished with two slip drawers so that the slip from the second drawer may be rapidly brought into use in the event of that in the first drawer running out. This can be done so rapidly that the interval between the insertion of two consecutive punched slips is ample for the purpose. It is also now the custom to redden a length of the slip near the end of the roll so as to give timely warning of its coming exhaustion.

A short chain is attached to the weight in such a way that when the weight is nearly run down a bell is rung, thus warning the key clerk that it should be re-wound.

Motor and Train.

The receiver consists of two separate parts, the motor and the train. The former comprises the slip drawers and, as its name implies, the weight and winding and driving axles. By means of a catch at the back, the driving axle, which is furnished with a ratchet wheel, can be held by moving over the pawl seen to the right of the front chain wheel. The train can then readily be removed from the motor and another substituted. This is obviously a much more expeditious process than removing the instrument as a whole.

Winding of Coils.

The windings of the coils and their terminals are shown in Fig. 144. The use of a single winding of correspondingly thicker wire, instead of the two windings placed in parallel, would give a slightly better figure of merit. Upon the other hand the arrangement described no doubt facilitates differential adjustment.

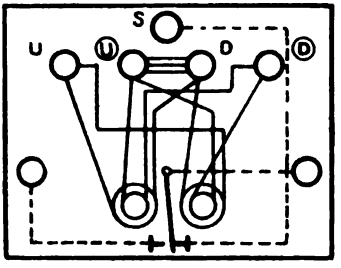

Fig. 144.—Connections of receiver.

Adjustment.

The lower armature is furnished with a platinum-tipped extension for completing the local circuit of the sounder. The adjustment of the instrument is fortunately quite simple, but it must be remembered that two conditions have to be fulfilled, viz. that both the printing and the sounder marks should be correctly received. By improper adjustment it frequently happens that only one of these conditions is fulfilled. The inking discs should be kept clean, since more play is required and a slower speed of working otherwise results. The best method of adjustment is as follows:—

1. Place the spacing screw in its central position.
2. Adjust the left contact screw until, when the tongue is put over to the left, a broken line of dots appears upon the slip, continue this until the point is reached where a full line is just obtained, and give a further slight turn to the screw in order to provide a margin.
3. Close up the right contact screw until the continuous line is just cleared when the tongue is moved to the right. Then give a further slight turn to the screw to provide a margin.

The final adjustment to the instrument may be made by the spacing screw from observation of signals transmitted at the full speed. The adoption of this systematic method will be found to result in better working and greater permanency of the adjustment when once made.

Spring Receivers, Speed of Slip, and Figures of Merit.

The earlier forms of Wheatstone receiver were worked by a spring instead of a weight, and many of these instruments are in use at the present time upon less important circuits. They may be used in any case where the maximum speed required does not greatly exceed 200 words per minute. The speed of the slip when the lever is in the position for slowest speed should not be more than 8 feet per second, and at highest speed not less than 36 feet a second. The speeds of the slip with a weight-driven receiver should range from not more than 8 to not less than 60 feet per second. The resistances of the coils are in each case the same, viz. 100Ω each, *i. e.* 200Ω in series and 50Ω in parallel. The figures of merit are also the same, 10 m.a. with the coils in parallel for key speed working, and 17·5 m.a. for the maximum speed of each instrument, but in this case a shunted condenser is employed, and the coils are placed in series.

THE SHUNTED CONDENSER, SELF-INDUCTION, AND TIME-CONSTANT.

It is possible to very greatly reduce the retarding effect of self-induction by the use of a resistance and condenser of suitable values. The condenser is placed across the terminals of the resistance, and the arrangement as a whole is usually termed a "shunted condenser."

Before tracing the causes of the action mentioned it is desirable that the effect of self-induction in delaying the rise of the current should be carefully examined. Let a battery, key, and an inductive resistance (a resistance having self-induction) be joined up in series. The value of the current given by applying Ohm's law represents the final or full value, but at the instant at which the key is closed the current is zero. The time taken for the current to rise to its full value or to any given percentage of its full value depends solely upon the self-inductance and resistance of the circuit. It is therefore quite independent of the value of the E.M.F. or current used. The "time-constant" of such a circuit is defined as the time in seconds

taken for the current to rise to ·632 (roughly $\frac{2}{3}$) of its maximum value, and is equal to the self-inductance (in henries) divided by the resistance (in ohms) of the circuit.* Assuming that the self-inductance, say 3 henries, is constant, and that the E.M.F. and resistance acting in the circuit are respectively 12 volts and 500ω the time-constant is $\frac{3}{500}$ = ·006 second. This is the time taken for the current to rise to approximately $\frac{2}{3}$ of its full value *i. e.* to $\frac{2}{3}$ of $\frac{12}{500}$ ampere = 16 m.a. Had the E.M.F. of the battery been 24 volts the current would have been 32 m.a. ·006 second after the circuit had been completed.

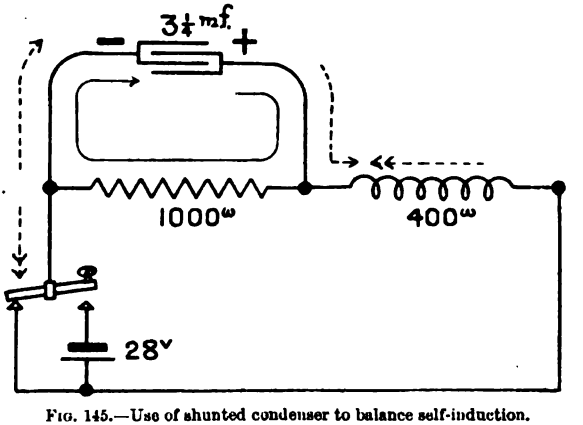

FIG. 145.—Use of shunted condenser to balance self-induction.

It will be seen that any particular value of current may be obtained in any given time provided a large enough E.M.F. is employed. For instance, the current in the circuit described would be 16 m.a. in ·0006 second had 84·2 volts been used, or in ·00006 second with 162 volts.

USE OF SHUNTED CONDENSER TO BALANCE SELF-INDUCTION.

In Fig. 145 an *A* relay having a self-inductance of 3¼

* Where an electromagnet with an iron core is concerned the self-inductance depends upon the value of the current, since the permeability of the iron varies with different values of magnetizing force. The self-inductance, of course, decreases due to the reduction of the permeability as the magnetizing force increases.

henries is shown in series with a shunted condenser, battery, and key. The capacity and resistance of the shunted condenser have been so arranged, that, when the key is released after depression the discharge of the condenser balances that of the relay. Whilst the key is depressed the condenser is charged by the difference of potential (20^{v}) existing between the ends of the 1000$^{\omega}$ resistance. If now the key is released the condenser discharges through the 1000$^{\omega}$ resistance, but in parallel with this is the 400$^{\omega}$ relay. The relay, having self-inductance, would generate an E.M.F. in the direction indicated by the dotted double arrow tending to prolong the main current. This E.M.F. is exactly balanced by that existing between the ends of the 1000$^{\omega}$ resistance depicted by the dotted single arrows. The current therefore sinks to zero at once, and prolongation of the current due to self-induction is eliminated.

Whenever an arrangement having self-induction is balanced by a shunted condenser as described, the following relation always exists :—

The self-inductance in henries is equal to the product of the capacity in farads, and the square of the resistance shunting it, in ohms.

In the present case the self-inductance (L) of the relay

$$= \cdot 00000325 \times 1000^2 = 3 \cdot 25 \text{ henries}^{*}$$

The shunted condenser not only secures that the current through the electromagnet shall not be prolonged but it also hastens the rise of the current. It has previously been explained that a condenser connected across a resistance acts as a short circuit upon that resistance until charged. Taking the case of Fig. 145, the difference of potential between the ends of the relay (assuming the battery resistance as nothing) is 8 volts when the current has attained its full value of 20 m.a. But at the instant at which the key is depressed, this difference of potential is equal to the full E.M.F. of the battery, viz. 28 volts. From the investigations of page 314 it will be obvious that the

* The value of the current used must also be stated for the reason indicated in the foot-note upon the previous page. The self-inductance of an *A* relay with coils in series is 3¼ henries at 20 m.a.

current rises at a far higher rate than it would if the condenser were disconnected and the difference of potential between the ends of the relay did not exceed 8 volts.

When the condenser is fully charged the whole of the current passes through the 1000$^{\omega}$ resistance. Between this condition and that resulting at the instant when the key is depressed there are, of course, intermediate conditions. The action of the condenser can be made quite apparent by imagining that it is replaced by a resistance which increases in value from nothing to infinity (disconnection) during the time which the condenser takes to become fully charged. From this it is obvious that the difference of potential across the relay falls from 28 volts at the instant when the key is depressed to 8 volts when the condenser is fully charged.

Action of Shunted Condenser in Wheatstone Working.

In high-speed Wheatstone working a shunted condenser is invariably employed to enhance the speed of working. Upon a long circuit or upon one having considerable capacity its beneficial effects are produced by its action with or upon the static charge of the line. The general principle of the action can readily be explained but the rigorous mathematical proof is quite beyond the scope of the present work.*

The shaded triangle in Fig. 146 represents the value and distribution of the charge existing upon the wire when the positive pole of the battery is connected to line. The condenser is also charged in the direction indicated. At the instant when the battery is reversed and is connected as shown the conditions illustrated in the figure obtain. The condenser discharges into the line, thus producing a current through the receiver in the direction of the reversed battery and shown by the double-arrow. It must not be overlooked that the receiver possesses a considerable amount of self-induction and that, at the moment of reversal of the battery, the E.M.F. due to this cause comes into play in such a direction as would, in the

* The proof is given in an article in the *Electrical Review* of 3rd September, 1886, by W. Moon.

absence of the shunted condenser, facilitate the passage of a portion of the static charge upon the line through the receiver coils so causing prolongation and thereby diminishing the speed of working by reason of the increased time taken for the current in the receiver to change in direction. Even supposing that the receiver had negligible self-inductance, the shunted condenser would still produce highly beneficial results since it would reverse the current in the receiver immediately the battery was reversed and would prevent the line from discharging through the receiver. Under existing practical conditions its action is

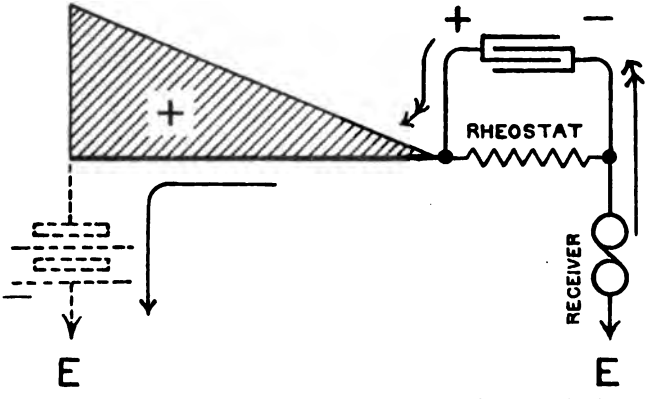

FIG. 146.—Principle of shunted condenser used upon a Wheatstone circuit.

firstly to prevent the line discharging through the receiver —a tendency which would be aided by the E.M.F. of self-induction—and, having eliminated this, secondly, by its continued action creates a difference of potential across the terminals of the receiver which causes the current to rapidly rise to its full value in the reverse direction—in fact this happens before the positive charge upon the line has been reversed in sign. The condenser acts instantly the battery is reversed and only ceases to act when fully charged in the reverse direction. It may be noted that the period of disconnection during which the lever of the transmitter is crossing from side to side is so small that the condenser is almost fully charged,

since there is not time for it to discharge through its shunt.

It will now be well to examine the effect of using too much and too little capacity in the condenser. The direct consequence of wrong adjustment is, of course, a reduction in the speed of working, but the effect upon the marks received may profitably be considered.

In the Morse systems, whether automatic or key, the elementary signals (dots and dashes) are of unequal length. A dash means that the battery is applied for three times as long as for a dot. If, therefore, the letter *N* is sent the spacing current following the dash may not reverse the charge upon the line and therefore the dash and the succeeding dot would run together, whilst *A* would probably be transformed into *T*: *i. e.* a dot, following a spacing current of a duration equal to a dash, would be lost entirely. Again, a "*B*" might be transformed into *G*. It is this effect which the shunted condenser greatly remedies by coming into action instantly the battery is reversed. With too little capacity, then, a dot following a dash run together and a dot following a long space is lost.

If now the capacity of the condenser is too great the last dot of an "*N*" would disappear, and the dot and dash of an "*A*" would run together. In submarine telegraphy this phenomenon is of frequent occurrence and is termed "over-curbing" in contradistinction to the case first cited in which the capacity was too little, termed "under-curbing."

For any particular circuit there is always a best value to give to the capacity and resistance of the shunted condenser and this may readily be found by the passage of working signals.

Adjustment of Shunted Condenser.

The resistance in the shunted condenser usually approximates to the resistance of the rest of the circuit and the value of the capacity required is then obtained by the passage of working signals at the maximum speed at which the circuit can be worked. The value will be found to vary for each particular circuit, generally speaking the longer the circuit the higher will be the capacity required. Where, however, the capacity is very great a smaller

current and a much higher shunt resistance gives better results.

The value of the current received with the switch turned should be 16 m.a. with the coils in parallel and the resistance in the rheostat should be reduced until this current (35° on the differential galvanometer with its coils in parallel) is obtained; with the receiver in series 8 m.a. (20° on the galvanometer) only is required. If the resistance in the rheostat has to be lowered to an amount altogether out of proportion to the resistance of the rest of the circuit the power should be increased.

Action of Shunted Condenser upon a very Short Circuit.

The beneficial action of the shunted condenser is usually ascribed to its effect in neutralizing or rather mitigating the effects of self-induction in the receiver coils. This is however only true where the circuit is very short and has practically no capacity.

Upon such a circuit, having little or no capacity, a shunted condenser effects a small economy in battery power. By disconnecting the condenser and increasing the battery power the same speed can be obtained as with the condenser. The effects of self-induction can always be smothered by introducing resistance into the circuit and raising the battery power. The time constant of the circuit may be thus reduced to any required extent. For instance the time constant of a circuit containing a battery (100$^{\omega}$ resistance) and a receiver in series is $\frac{3{\cdot}25}{500}$ = ·0065 second, with a resistance of 1500$^{\omega}$ added it is $\frac{3{\cdot}25}{2000}$ = ·001625 second.

Resistance of Sending Circuit.

It has previously been stated that each coil of the differential galvanometer (50$^{\omega}$) is shunted by a 300$^{\omega}$ resistance coil in order to reduce the self-inductance. It is also pointed out in the subsequent chapter that one of the chief advantages gained by bridge duplex working lies in the fact that the currents sent out do not encounter the self-

inductance of the home receiver. Moreover, the beneficial effect of the signalling condenser is accountable to its action in temporarily reducing the effective resistance of the sending circuit. In order that a signal may be formed upon the distant receiver in the shortest possible time, the

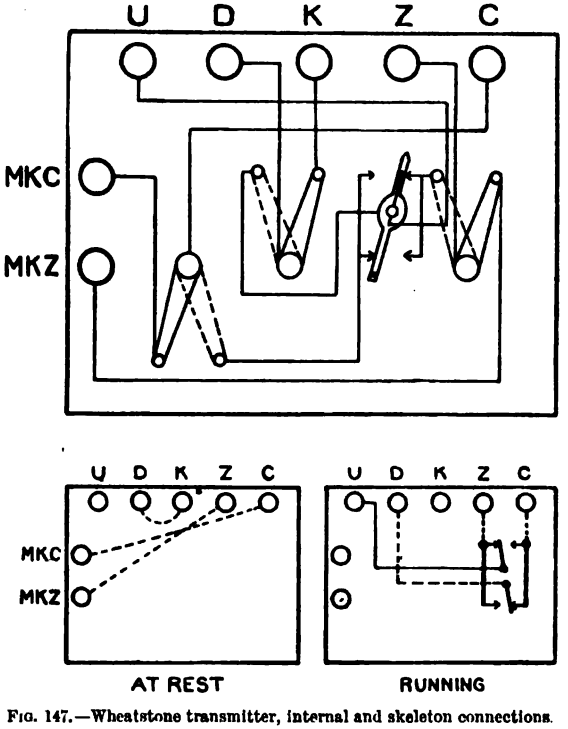

FIG. 147.—Wheatstone transmitter, internal and skeleton connections.

resistance of the sending circuit should be as low as possible, subject to the qualification that it shall not be so small as to cause the transmitter to spark (see page 513). The effect of self-induction in the sending circuit is even more serious, and it is upon this account that the coils are shunted as already explained. They are also invariably joined up in parallel, thereby reducing both the resistance

and self-inductance of the instrument to one-fourth of the value which it would have with the coils in series.

It will now be realized that the use of Daniell batteries upon a Wheatstone circuit would result in a serious reduction of the working speed owing to the larger internal resistance involved in providing the requisite E.M.F. With Bichromate batteries the minimum resistance per cell (2ᵐ) is sometimes termed the "sparking point," whilst the maximum value (4ᵐ) is termed the "speed point."

Transmitter Switch.

The lever provided for stopping and starting the trans-

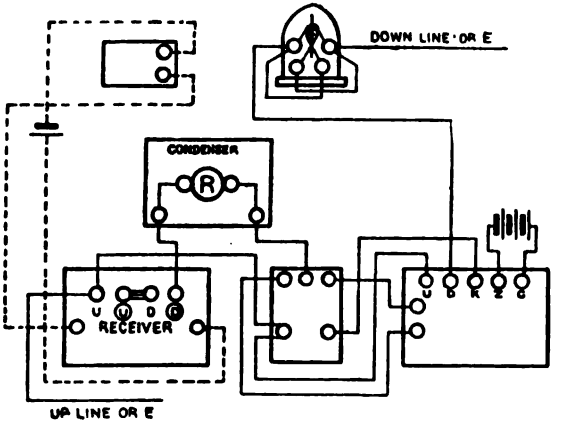

Fig. 148.—Wheatstone simplex connection.

mitter also operates the switch referred to on page 307. When the transmitter is not actually running this switch joins the battery through to *Z* and *C* of the double current key provided for making or answering calls and for the sending of acknowledgments. Also it joins the down line through to the lower left terminal of the key. The connections of the transmitter with its switch are depicted in Fig. 147. The switch consists practically of three two-way switches mechanically connected together. The first and third levers in the positions shown join the battery terminals *Z* and *C* through to *MKZ* and *MKC*, which are connected to *Z*

and *C* of the key. In the other position (when the transmitter is started) the battery (at *Z* and *C*) is connected to the battery contact screws, thus forming the connections depicted in skeleton in the lower right-hand portion of Fig. 147. The second lever normally connects the down line, which has passed the galvanometer, through to *K*, which is in turn connected to the lower right terminal of the key. In the other position the down line is joined to the lower half of the divided lever. The up line terminal of the transmitter *U* is connected to the right side of the key and *U*-circle of the receiver or relay as the case may be. Comparison of Figs. 148 and 98 will show that when the transmitter is stopped the connections are practically those of the double current sounder save that a shunted condenser is included and a receiver substituted for the relay.

Connections of a Full Wheatstone Set.

The connections of a full Wheatstone set are depicted in Fig. 148, and, with the aid of the above explanation, they should be sufficiently clear and easy to memorize.

The path of a received spacing current is from the down line through the galvanometer to *D* of the transmitter, to *K*, to lower right terminal, and to centre of the key, through the shunted condenser and receiver, to the up line.

The transmitter currents are sent out between *U* and *D* of the transmitter, and, to make a mark, the positive pole of the battery is joined to *D* and the negative to *U*. The key currents should require no comment.

Adding a Transmitter to a Key-worked Circuit.

In order to add a transmitter to a key-worked circuit to meet a temporary requirement a transmitter stool should be obtained so as to avoid cutting the tables to receive the weight chains. The two wires upon *Z* and *C* of the key should be removed from their terminals and extended by pieces of wire respectively to *Z* and *C* of the transmitter. The wire upon the lower right-hand terminal of the key should similarly be disconnected and then joined to *D* of the transmitter. *K* should then be connected to the lower right terminal of the key. Finally, *U* of the transmitter

should be joined to the lower left terminal of the key, leaving the wire already upon that terminal in its position.

Substitution of a Receiver for a Relay.

In substituting a receiver for a relay a similar procedure should be followed. If a spring receiver will not meet the case as regards the speed required a stool should be obtained in preference to cutting the tables for temporary requirements. It should be noted that the *U* terminal of the receiver is on the left, whilst on a relay it is on the right. This is of course due to the fact that in the former case the tongue normally lies over to the left. The wire on

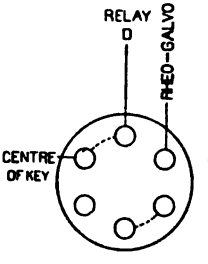

Fig. 149.—Duplex switch connections upon a key worked circuit.

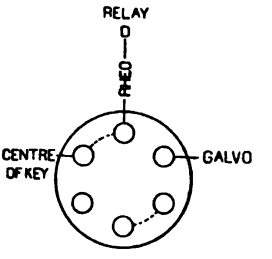

Fig. 150.—Duplex switch connections for a Wheatstone duplex circuit.

U-circle of the relay is joined to *D*-circle of the receiver, and the *D* wire to *D*-circle. The local circuit is quite obvious.

THE WHEATSTONE DUPLEX.

The Wheatstone system can be duplexed upon either the differential or bridge methods, and the connections required in the former case may readily be deduced by comparing Figs. 148 and 117. There are, however, three points which require to be especially noticed. Firstly, a battery switch is provided for cutting out the battery and inserting a resistance equal to its internal resistance. In the older arrangements this was accomplished

by means of a 6-terminal two-position switch of the same type as that used to convert the set from simplex to duplex (see Fig. 153). In later arrangements a two-way switch serves the same purpose, the negative pole of the battery being connected to *Z* of the transmitter, and also to one side of the battery resistance coils. The positive pole of course takes the opposite side of the two-way switch, the lever being joined to *C* of the transmitter. Secondly, the condenser and rheostat are in circuit at simplex, so that

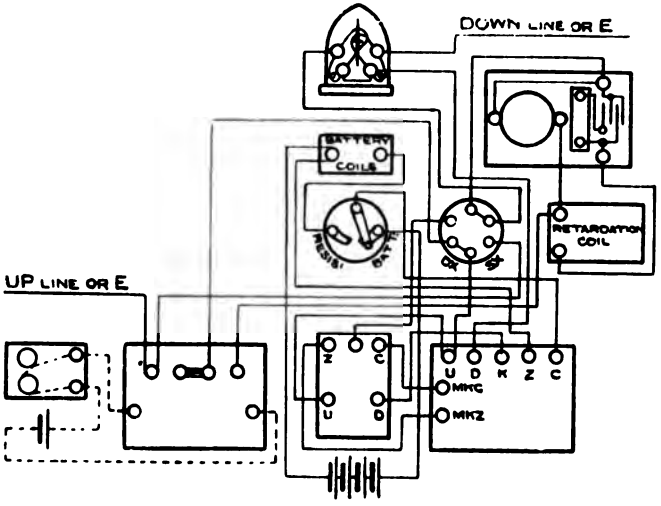

FIG. 151.—Connections of a Wheatstone duplex circuit.

the arrangement may be used as a shunted condenser and so provide a higher working speed. This is effected by a slight alteration in the connections upon the duplex switch. Referring back to Fig. 117 of the double current duplex connections it will be seen that *D* of the relay is joined to the top centre of the duplex switch, the upper left terminal of which goes to the key and the right to the rheostat. Now in order to have the condenser and rheostat in circuit for both simplex and duplex, it is only necessary to join them between *D* of the relay and the centre terminal of the rheostat and take the right terminal

direct to the galvanometer. The alteration necessary is shown in principle in Figs. 149 and 150. Thirdly, in order that the adjustment of the receiver may be the same for both duplex and simplex working a resistance coil is inserted between the *U* terminal of the receiver and junction of the two wires connected to it. When the resistance of the line is 1000Ω or less a 1000Ω resistance coil is used, but where the line resistance exceeds this amount 2000Ω is inserted. It will therefore be seen that although the received current passes through both coils in series the resistance of the circuit is practically doubled, thus halving the current and so making its magnetic effect upon the receiver practically the same as in duplex working.

The connections of the receiver which replaces the relay are quite obvious and those of the transmitter are readily deduced from the simplex Wheatstone set already described. Transmitter *U* and the lower left terminal of the double current key are joined together to the lower centre terminal of the duplex switch. The galvanometer split wire comes to *D* of the transmitter and is normally passed on to the lower right terminal of the key viâ *K*. If the above explanations are clearly apprehended the connections of a Wheatstone duplex are as easy to remember as those of a double current duplex. The connections are shown in full in Fig. 151.

DIFFERENTIAL DUPLEX WITH SIGNALLING AND READING CONDENSERS.

An improved form of Wheatstone differential duplex is occasionally used upon cable circuits, and consists in the addition of signalling and reading condensers to the ordinary duplex arrangements. The duplex connections are accurately shown in skeleton in Fig. 152. Two resistances each of 3000Ω are placed in series with each coil of the receiver, and their junction forms, as the case may be, a splitting or combining point for the key currents. The two signalling condensers are joined between this point and the ends of the two coils of the receiver. This action is identical with that of the signalling condenser used in bridge duplex working (see page 338), viz. to

apply the full E.M.F. of the battery to the line until the current in the distant apparatus has risen to the value which is obtained when the condenser is charged and the duplex resistance coils are traversed by the current (the E.M.F. applied to the line is then less than the full E.M.F. of the battery).

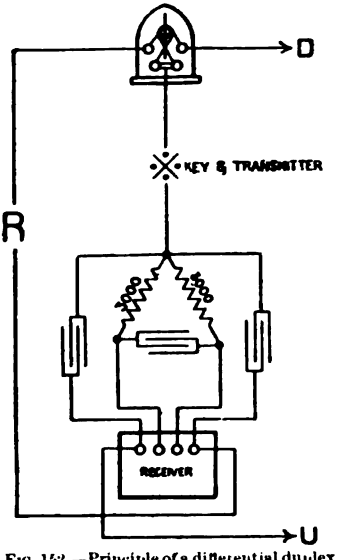

FIG. 152.—Principle of a differential duplex with signalling condensers.

The reading condenser is to hasten the rise of the received current by short circuiting the duplex coils until charged. Also it reduces the short-circuiting effect of the signalling condensers upon the received signals.

All the condensers assist the reversal of the current by their discharges. They, as it were, "suck out" the static charge upon the line.

The full connections of the set are indicated in Fig. 153, and will readily be comprehended by aid of the skeleton diagram and the previous consideration of Wheatstone working as a whole.

NEWS CIRCUITS AND BATTERY POWER REQUIRED.

For "news" circuits a transmitter is required at the sending station, and receivers at the terminal and intermediate stations. The terminal station only is provided with a shunted condenser. In practice a minimum of 100 volts (secondary cells) or its equivalent in primary batteries is employed, and the resistance of the circuit is, if necessary, raised by the rheostat upon the shunted receiver until that current is attained.

The reason for employing a minimum E.M.F. of 100 for operating Wheatstone circuits lies in the fact that

with lower voltages the resistance of the contacts made by the divided lever of the transmitter have an abnormally high value, so reducing the current to too small a value for high speed working.

Upon full Wheatstone circuits Bichromate cells are invariably employed when primary batteries are used. In the case of circuits consisting of a transmitter at one end, only Bichromate batteries are employed for the transmitter, but at the receiving stations Leclanché No. 1 cells with circular zincs are quite adequate. They are only

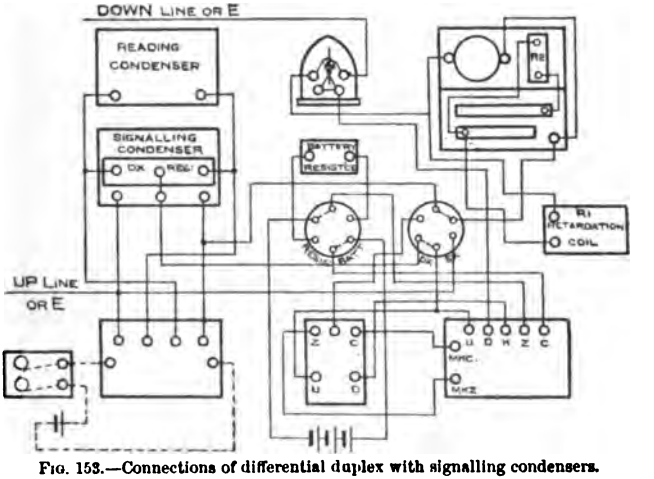

FIG. 153.—Connections of differential duplex with signalling condensers.

used to call, send acknowledgments, or to ask for corrections.

In duplex working a minimum of 100 volts E.M.F. is employed for the reason given in the case of simplex circuits. It is only where the cost of providing additional circuits would be prohibitive that duplex Wheatstone working is normally adopted. It is, however, quite frequently provided to meet any sudden pressure of work, such, for instance, as that caused by other circuits becoming faulty.

The local battery in every case consists of either a 2-cell Bichromate or a 3-cell Large Daniell.

THE STEVENS AUTOMATIC.

The electrical and magnetic portions of the receiving instrument are practically identical with those of the Wheatstone receiver which it replaces. Instead of the received signals being represented by inked marks, the slip is perforated with longitudinal long and short holes according to the duration of the marking currents. The instrument is driven by an electro-motor and the electrical portions are employed solely to control the action of the punch. A plunger moves rapidly up and down by the action of an eccentric. This plunger, which is normally held above the uniformly moving oiled paper slip by a suitable spiral spring, works in a slot upon the punch. Immediately a marking current is received the armature axle and the lever which it carries move over. This lever, or rather an extension of it, now passes into the slot in the punch, so connecting the plunger and punch. This causes the rapidly reciprocating punch to perforate the slip. The punch, of course, goes on perforating the slip and thus increasing the length of the perforation until the current through the coils is reversed and the link between the plunger and the punch is withdrawn.

The slip, having holes of a length corresponding to the dots and dashes, is then passed through an instrument which produces corresponding signals upon a sounder. This is accomplished by two bell-crank levers placed side by side and joined to one side of the battery with the end of the sounder connected to the contact point upon which they act. The levers are adjusted so that when the unperforated paper prevents them from moving upwards the local circuit is broken. When, however, a perforation is met the levers move upwards and the local circuit is completed.

By a similar mechanism double current signals can be obtained by passing the perforated slip through the specially designed transmitter. It would therefore be possible to avoid re-punching items of news at a transmitting centre. The perforated received slip would be passed through the transmitters of the offices requiring the item and then passed through the sounder apparatus and written down from sound for delivery to the local papers.

The speed of reception is at present about 80 words per minute, but there seems little reason why this should not be increased. It is, however, true, that the speed at which the punch at present moves is extremely great.

Another point is that the slip for the special transmitter may be perforated by signals sent from an ordinary key, thus avoiding the necessity for the special skill which is required to perforate slip for an ordinary Wheatstone circuit.

The original object of the invention was to enable the received slips to be read by sound instead of by eye, as it is well known that the latter process is far slower than the former.

The apparatus is still in the experimental stage, but it may possibly be of use for race meetings if the working speed can be considerably increased.

CHAPTER X

THE BRIDGE DUPLEX.

THE Bridge duplex system is invariably used for Wheatstone working upon cable circuits. Upon such lines, where the capacity is much greater than upon open lines, a higher speed of working is attained than that which results when the previously described differential duplex is employed. For even the longest aërial lines it possesses absolutely no advantage over the differential system, but on the contrary entails the use of larger battery power.

Advantages of the System.

The enhanced speed of working upon cable circuits is due to the fact that the sender's current does not pass through the relay or receiver at the sending end and to the application of signalling and reading condensers.

The advantages of the bridge system may be summarized as under:—

1. Permits the application of signalling and reading condensers.
2 The minimum amount of retardation is introduced in the sending circuit, since the current flows direct to line and does not pass through an electromagnet at the sending end.
3. The apparatus required need not be differentially wound.
4. Two different types of instrument may be worked upon the one circuit.
5. The effects of earth currents are not felt so much in bridge as in differential duplex working.

The advantages gained under headings 1 and 2 result

in a considerable increase in the speed of working, but at the expense of increased battery power. The advantage of using apparatus not differentially wound is in this country quite problematical, since all the relays used by the Post Office are invariably so wound. The fourth claim is true but it does not seem probable that it could ever be desired to work, say, Morse in one direction and Hughes in the other. The fifth point will be apparent when it is remembered that the resistance of the circuit as a whole is very high, and that only a portion of the line current passes through the receiver.

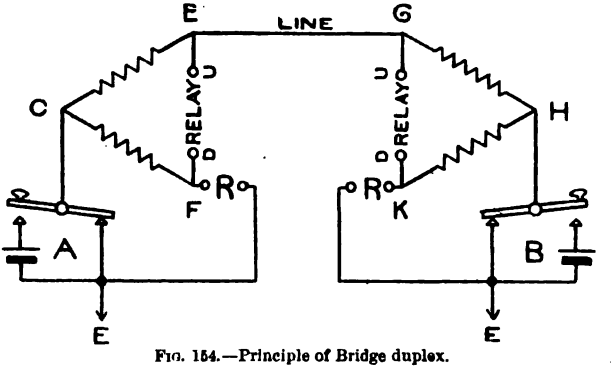

FIG. 154.—Principle of Bridge duplex.

GENERAL PRINCIPLE.

After the detailed consideration accorded to the differential duplex but little difficulty will be found in dealing with the bridge duplex. The differential system consists in splitting the sending current through the two coils of a differentially wound relay, the effects produced being the result of disturbances of the balance of current in the two coils. In the bridge system the current divides through two resistance coils to the line and compensation circuits between which the receiving apparatus is placed. If the ends of the two resistance coils are at the same potential no current will flow through the receiver. Hence it is usual to say that the differential system depends upon a balance of currents and that the bridge system in contradistinction depends upon a balance of potentials.

The connections depicted in Fig. 154 illustrate the fundamental principle of this system as compared with the differential duplex (see Fig. 100).

CE and *CF* are two equal resistances, between which the receiving apparatus is connected. *R* represents a resistance equal to that of the line *plus* the resistance of the distant apparatus. The connections at both ends are identical, *GH* and *HK* corresponding to *CE* and *CF*.

If the key at *A* is depressed the current divides equally between *CE* and *CF* because the resistance of *R* is equal to that of the line and *B*'s apparatus. Since the resistances of *CE* and *CF* are equal, the differences of potential between *C* and *E* and between *C* and *F* are equal, consequently, when only one key is depressed, no current flows through the relay, and the sender's signals do not therefore affect his apparatus.

The path of the compensation current is from the positive pole of the battery to *C* along *CF* through the rheostat back to the negative pole of the battery. The line current flows from the positive pole of the battery through *CE* along the line to *G*. At this point the current divides, one portion passing through the relay in the direction *U* to *D* and along *KH* to *H*, and the other along *GH* to *H* where the two parts reunite and pass through the back contact of the key to earth and thence to the negative pole of the *A* battery. The mark is produced by that portion of the current which passes through the relay. The rheostat circuit may in this instance be regarded as a high resistance shunt across *KH*, which therefore somewhat reduces the resistance between *K* and *H*. The main path of the received current is along *GH* with the relay and the joint resistance between *K* and *H* placed in series across *GH*. The current through the relay is therefore rather less than half of that arriving at *G*.

If the key at *B* is depressed instead of that at *A* the current divides equally between *HG* and *HK*, so producing equal potentials at *G* and *K*. The line current passes to *E*, along *EC* and the path in parallel with it (*EFC*), to earth, and so back to the battery at *B*. The path in parallel with *EC* is the relay in series with the combined resistances of *CF* and *R*.

When both keys are simultaneously depressed the batteries oppose each other in the line and the current at *A* flows along *CF*, with *CE* and the relay joined across it, through the rheostat to the negative pole of the battery. The portion of the current taking the path of *CE* and the relay produces the mark. Similarly the mark at *B* is produced by that portion of the current from *B*'s battery which takes the path through *GH* and the relay.

Intermediate Position of the Key.

The intermediate position of a key during the continuous depression of the distant key throws the rheostat into the line circuit and the received mark is made by the current flowing through the relay, shunted by *CE* and *CF* in series, and through the rheostat to earth. The received mark is therefore not interfered with. At the sending end the balance is upset and the relay tends to mark, but the current flowing through it is much less than in any of the cases considered. The position of the key when touching neither front nor back stop is only of momentary duration and does not produce any serious effect upon the working of the arrangement.

Resistance of the Arms or Duplex Coils.

In the arrangement considered the resistances *CE* and *CF* have been given equal values, but this is not essential. Equality of potentials will be produced at *C* and *E* if the product of the resistances of *CE* and the rheostat is equal to the product of those of *CF* and the line circuit (including distant apparatus). This fact may readily be proved by a consideration of the principle of the Wheatstone bridge (*q.v.*). If *CF* and *R* are greatly increased in value in comparison with *CE* and the line circuit the value of the current sent to line is considerably increased, whilst the proportion of the current received passing through the relay when receiving is correspondingly reduced. The best values can, in any particular case, be mathematically determined, but it will suffice to say that under the conditions in which the system is employed by the Post Office the values are fixed at 3000$^{\omega}$ each.

Double Current Working.

As in the differential system, the batteries may be made to combine when both keys are depressed, so producing twice as much current in the line as in the compensation circuit. By utilizing this and the opposition effects double current working is readily obtained. Moreover it presents the advantage that the apparatus connections terminate in an up and a down line terminal dealt with in precisely the same way as in the single needle and

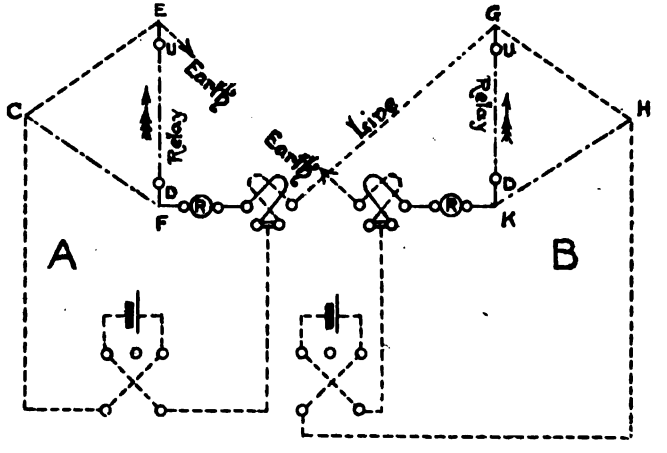

Fig. 155.—Skeleton connections of bridge duplex, keys at rest.

other forms of apparatus. The actual connections of a Post Office bridge duplex are depicted in skeleton in Figs. 155 and 156. The paths of the currents have been distinctively shown in order to facilitate the comprehension of the somewhat complex derived circuits.

Both Keys at Rest.

With both keys at rest (Fig. 155) the batteries at *A* and *B* combine together in the line circuit. The path of the main current, shown by a dotted line, is from the positive pole of *A*'s battery through *CE*, with *CF* and the relay in series across it, to earth, through one coil of *B*'s galvanometer, joining with *B*'s battery through *HG*, with *HK* and

the relay in series across it, along the line, through *A*'s galvanometer back to the battery. The relay and *CF* is in parallel with *CE*, and a part of the current therefore passes through this path in the direction *D* to *U*, so causing the relay to space. Similarly *B*'s relay spaces by the portion of the current flowing viâ *HK* and the relay. These paths are indicated by dot-dash lines in contradistinction to the simple dotted lines of the main circuit.

It should be noticed that a current rather less in value

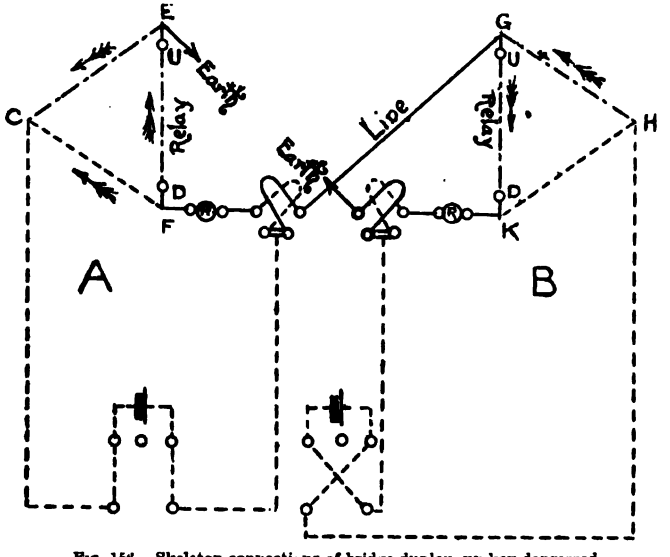

FIG. 156.—Skeleton connections of bridge duplex, up key depressed.

than that through *FC* passes through the rheostat. This point can, however, only be made apparent by consideration of the actual numerical values of the current as given on page 342 *et seq.*

ONE KEY ONLY DEPRESSED.

In Fig. 156 the key at *A* is shown depressed whilst that at *B* is at rest. The two batteries here oppose each other in the line, and the relays are each affected by the compensation current derived from the ends of the duplex

resistance coils included in the compensation circuits at either end. At *A* the path of the current is from the positive pole of the battery through one coil of the galvanometer, through the rheostat, *FC* (with the relay and *EC* in series across it), and back to the negative pole of the battery. The relay spaces with the current shunted from *FC*. At the distant end the relay marks with the current shunted from *HK*. The derived circuit is shown by a dot-dash, and the main circuit by a dotted line. It will be seen that the effects produced at the two ends of the circuit are opposite in character, because the direction of the current at *A* is opposite to that at *B* due to the different positions of the two keys.

Both Keys Depressed.

When both keys are depressed the paths and values of the currents are identical with those of Fig. 155, but in this case the direction of the current is everywhere reversed, and both relays consequently register a mark instead of a space.

Intermediate Position of the Key.

If *B*'s key is at rest and *A*'s key is released the latter momentarily occupies an intermediate position, the effect of which is to greatly reduce the value of the marking current flowing through *B*'s relay, whilst leaving the spacing current in *A*'s relay practically unaffected. It will be observed that the received current traverses *A*'s rheostat, and that the relay is shunted by *FC* and *CE* in series.

Compensation Circuit and Balancing.

Since the duplex resistance coils are of equal value, the current in the line and compensation circuits will also be equal if the distant battery is substituted by a resistance equal in value to its internal resistance. If two coils of a differential galvanometer are respectively placed in the line and compensation circuits a balance will be obtained with the galvanometer needle at zero, when the rheostat and condenser are accurately adjusted to the value of the circuit's capacity and resistance. This adjustment is made

in precisely the same way as in the case of the Wheatstone differential duplex, and is preferably accomplished with the distant two-way switch put to the earthing side.

The behaviour of the condensers and their discharging resistances in the compensation circuit is precisely the same as in the case of the differential duplex. The values of the line charges in the various positions of the keys are identical with those shown in Fig. 113, and the description of their effects upon the apparatus would be merely a repetition of the previous descriptions.

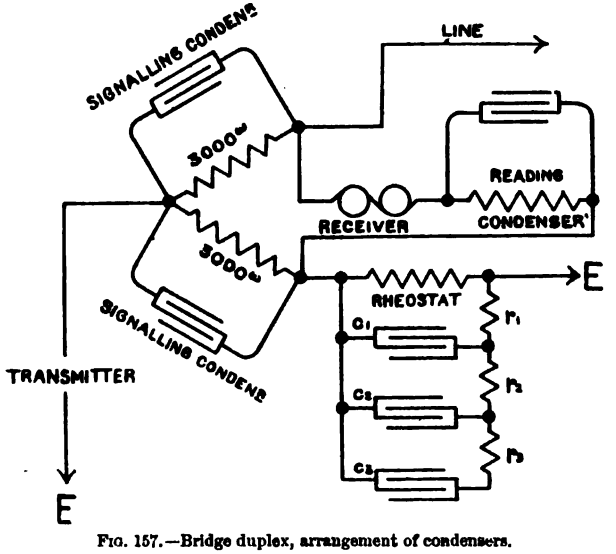

FIG. 157.—Bridge duplex, arrangement of condensers.

GENERAL ARRANGEMENTS.

The duplex resistance coils are contained in a box furnished with three terminals and two plugs. A signalling condenser is connected across each coil, but for economy of space the two condensers are placed in a single box provided with three terminals (Fig. 158). A shunted condenser is connected in series with the receiver across the ends of the duplex resistance coils as indicated in the skeleton diagram given in Fig. 157.

The Signalling Condensers.

The capacity of the circuit must always be satisfied before the current can attain its full value at the receiving end of the circuit. The time taken for the current to rise to its full value has already been explained to be quite independent of the E.M.F. employed. But the time taken for the current in the circuit to rise to *any given value* may be reduced by increasing the value of the E.M.F. applied. Therefore a signal may be produced by 100 volts in (very roughly) half the time that would be required by 50 volts, or in one quarter the time required by 25 volts—always provided that the maximum value of the current with the lowest E.M.F. was itself adequate.

In the bridge duplex the addition of the signalling condensers produces the advantages which would accrue from the use of nearly twice the battery power, but without its attendant disadvantages. The signalling condenser across the duplex resistance coil connected to line acts as a short circuit until it is fully charged. During this time the full E.M.F. of the battery is applied between the ends of the line, so producing a heavy rush of current into the line. When the condenser is charged, the current traverses the 3000$^{\omega}$ coil before reaching the line, and the E.M.F. applied to the ends of the line is less than the full E.M.F. of the battery by the amount taken up in overcoming the resistance of the coil. If the resistance of the receiving apparatus and the line is 3000$^{\omega}$ the E.M.F. lost in the duplex coil would be one-half the E.M.F. of the battery.

Since a signalling condenser is applied to the line circuit it will be obvious that in order to maintain a balance an exactly similar condenser must be applied to the compensation circuit.

Upon reversal of the current the discharge of the condensers combine with the battery which has been reversed, and the E.M.F. applied to the circuit is that of the battery *plus* the difference of potential due to the charge in the condensers. Until the condensers are discharged and charged in the reverse direction the duplex coils may be regarded as being short circuited. During the discharge of the condenser its "suck out" action is of enormous

value in hastening the discharge of the line. This action is technically known as the "curbing effect" of the condenser. The capacity of the condensers determines the duration of the effect, and the best value for any given circuit is obtained when the quantity of electricity in the condenser is equivalent to the charge upon the cable. If the capacity employed is excessive the current will rise to too large a value, and there will then be a reverse discharge of the line immediately the current is reduced to its normal value.

Summary of the Action of the Signalling Condensers.

To summarize the action of the condensers; they act as short circuits upon the duplex coils during charging. The reduction in the resistance of the circuit provides a correspondingly heavier flow of current which charges the cable more rapidly than the normal current. The condensers are adjusted so that the heavy current only lasts until the cable contains the same quantity of electricity which the normal current would supply. When the rush of current is over the normal current at once produces its effect at the distant end because the cable is fully charged. Upon reversal of the current the condensers act with the battery, and a heavy rush of current in the reverse direction results, so more rapidly discharging and recharging the line in the reverse direction.

Reading Condenser.

The shunted or "reading" condenser consists of a 14,000$^{\omega}$ three-coil resistance box (2000$^{\omega}$, 4000$^{\omega}$ and 8000$^{\omega}$ coils), and an adjustable condenser of the $7\frac{1}{4}$ m.f. type. The action of this condenser is entirely similar to that described upon page 316, but its importance is, if possible, even greater. A small portion of the first part of every received signal is lost by reason of the short-circuiting effect of the home signalling condensers. When the key at *A* is released the conditions of Fig. 156 are changed into those of Fig. 155. Now the first portion of the current flows from *A* along the line, through the signalling condenser across *GH* and through the battery to earth. In Hughes'

working this effect is of such serious consequence that signalling condensers cannot be employed. The reading condenser certainly mitigates this evil, and in Wheatstone working the rapid charging of the line, which is secured by the use of the signalling condensers, more than compensate for the deleterious effect upon the received signals.

Connections.

The actual connections of a Bridge Wheatstone duplex are shown in Fig. 158. The duplex switch is furnished

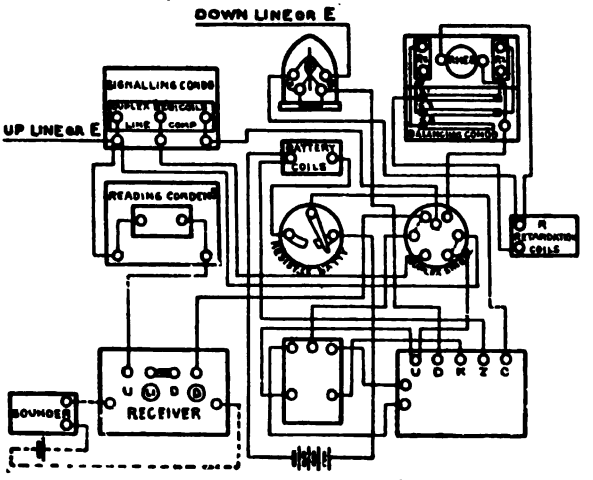

Fig. 158.—Connections of bridge duplex.

with seven terminals, and in the duplex position makes the connections shown by the dotted lines in Fig. 289, whilst at simplex the dotted connections (Fig. 158) are formed. The key and transmitter are joined up as previously described. The *D* terminal of the transmitter is connected to the galvanometer split, the right terminal of which is the down line terminal of the set. The left coil is connected through the rheostat, etc., to the duplex switch, where it joins the compensation duplex resistance coil and the receiver. The up terminals of the key and transmitter are connected through the switch to the centre of the duplex

coils. Thus the key and transmitter are connected between the galvanometer split and the centre of the duplex coils. The other side of the receiver is of course connected through the reading condenser to the line duplex resistance coil.

When the switch is turned to simplex the receiver is joined to the centre of the key and *U* of the transmitter is joined to the up line. The duplex coils need not be plugged up as they are no longer in circuit. The path of the received current is from the up line terminal through the reading condenser and shunt (the resistance of which should be considerably increased) and receiver, through the switch to the centre of the key, thence through *K* and *D* of the transmitter to the galvanometer. The path of a sent current is from *D* of the transmitter through the galvanometer to the down line, in at the up line and thence to *U* of the transmitter.

The connections and function of the two-way earthing switch are obvious. It should be noted that the rheostat and its condensers are cut out of circuit at simplex, but that the reading condenser is still available.

Self-Inductance of Apparatus at the Sending Station.

There is one other point which may with advantage be referred to, since it frequently results in a little confusion of mind. It has been stated that one of the advantages of the bridge duplex is that the current sent out does not have to encounter the self-inductance of the sender's apparatus. In Fig. 155 the paths of the currents are shown, and it might be thought that in this case the sending current is passing through the sender's apparatus. The correct way of regarding this is that the sender's own current is accurately balanced between *E* and *F*, and that the current which produces the effect at *A* is the current received from *B*. Similarly, the current flowing through the relay at *B* is that received from *A*, since *B*'s sending current is also balanced. Therefore the statement that the self-inductance of the sender's receiving apparatus is excluded from the sending circuit is quite true.

Calculation of the Current in each Part of the Circuit.

The calculation of the values of the current in the

various branches of the bridge duplex circuit is quite simple, but it involves some tedious arithmetical work.

The resistance of the battery is assumed to be nothing, and that of the shunted condenser and relay 2400Ω. The simplest method of dealing with the calculations is to consider each end separately, and to assume that the distant battery is for the time short circuited. When these calculations are completed it is only necessary to add the two results found for each part of the circuit.

Assuming that the battery at *X* is short circuited, it will be seen (Fig. 159) that a current due to 180 volts flows along *HG*, and the line to *E*. The current then divides, one part passing direct to earth (at *C*), whilst the other

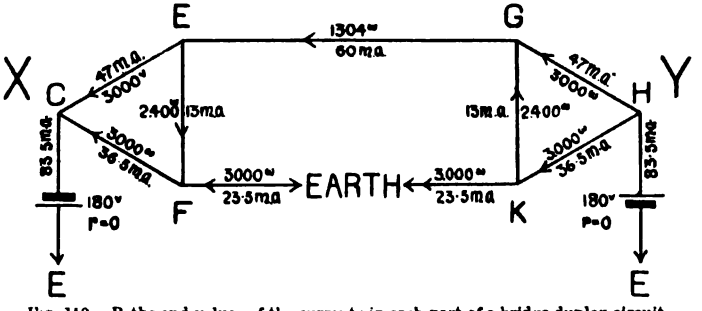

FIG. 159.—Paths and values of the currents in each part of a bridge duplex circuit with both keys at rest.

passes through the relay and then through *FC* and the *F*-Earth path in parallel. The circuit is in fact as shown in skeleton in Fig. 160.

$$\text{Resistance from } E = \frac{(2400 + 1500) \times 3000}{(2400 + 1500) + 3000} = 1696\Omega$$

Since *G* and *K* are at equal potentials with respect to the battery at *Y* (the *X* battery being regarded as short circuited), the total resistance of the line circuit for the battery at *Y*

$$= 3000\Omega + 1304\Omega + 1696\Omega$$

$$\therefore \text{Current} = \frac{180\Omega}{6000\Omega} = 30 \text{ m.a.}$$

As the resistance of the paths *EF*-Earth and the lower path (Fig. 160) are respectively 3900Ω and 3000Ω the currents

are in inverse proportion to those resistances, *i. e.* they are 13 m.a. and 17 m.a. respectively. The 13 m.a., however, divides into two equal parts at *F* as shown.

Imagining the battery at *Y* short circuited, and that at *X* acting, the current through *CE* and the compensation circuit is :—

$$\frac{180}{3000 + 3000} = 30 \text{ m.a.}$$

As the circuit is balanced an equal current flows along the line circuit and produces values at *Y* similar to those already found for *X*.

When both batteries are in action the currents are the sums of those previously found, viz. :—

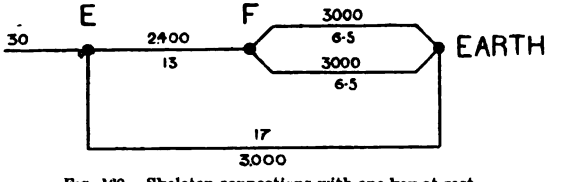

FIG. 160.—Skeleton connections with one key at rest.

In *CE* 17 (from *Y*) + 30 (from *X*) = 47 m.a.
„ *CF* 6·5 (from *Y*) + 30 (from *X*) = 36·5 m.a.
„ *F* Earth 30 (from *X*) − 6·5 (from *Y*) = 23·5 m.a.
„ *EF* 13 (from *Y*) = 13 m.a.

Through the battery 17 from *EC* due to *Y*
6·5 „ *FC* „ „ „
30 line current from *X*
30 compensation current from *X*

= 83·5 m.a.

The only point which calls for comment is in regard to the current in *F*-Earth. The direction of the compensation is opposite to that of the received current, and its value is therefore equal to the difference between them. The currents at the *Y* end may be obtained similarly, and are as shown in Fig. 159.

When one key is at rest whilst the other is depressed the conditions at each end are as shown in Fig. 161.

$$\text{Resistance} = \frac{(3000 + 2400) \times 3000}{(3000 + 2400) + 3000} + 3000$$
$$= 4929^{\omega} \text{ approx.}$$
$$\text{Total current} = \frac{180}{4929} = 36 \text{ m.a. approx.}$$

Current through relay and upper path
$$= \frac{3000}{3000 + 5400} \text{ of } 36 \text{ m.a.}$$
$$= 13 \text{ m.a. as before.}$$

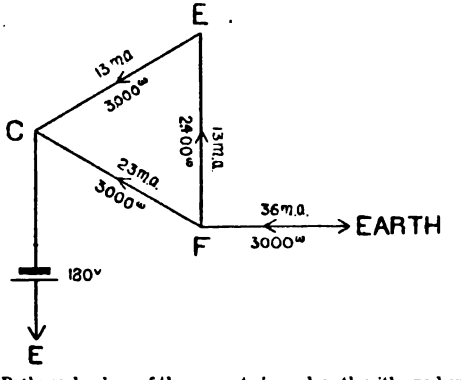

FIG. 161.—Paths and values of the currents in each path with one key depressed.

CALCULATION OF BATTERY POWER.

If it is required to ascertain what power must be employed to obtain a certain current through the receiver with a line of given resistance, it is first necessary to calculate the value of the resistance required to balance the circuit. This may be obtained from the following formula :—

$$R = \sqrt{\left\{\frac{a^2 S}{2a + S} + \frac{a^2 + aS}{2a + S} L + \frac{L^2}{4}\right\}} + \frac{L}{2}$$

where R = resistance required in the rheostat
a = resistance of each duplex coil 3000ω
S = resistance of receiver and in shunted condenser
L = resistance of the line.

For S = 400ω the formula becomes :—

$$R = \sqrt{\left(562500 + 1596\,L + \frac{L^2}{4}\right)} + \frac{L}{2}$$

and for $S = 2400^{\omega}$

$$R = \sqrt{\left(2571000 + 1929L + \frac{L^2}{4}\right)} + \frac{L}{2}$$

In the case illustrated $L = 1304$ and $S = 2400^{\omega}$

$$\therefore R = \sqrt{2571000 + 2515000 + 425000} + \frac{L}{2}$$

$$= 2347 + \frac{1304}{2} = 2999^{\omega}$$

which is very approximately correct.

Assuming that 13 m.a. is required through the relay and that Bichromate cells (E.M.F. = 1·82", $r = 4^{\omega}$ per cell) are used the number of cells required is found as follows :—

Referring to Fig. 161.

If the current through the receiver is 13 m.a. the current in the lower duplex coil is clearly $\frac{5400}{3000} \times 13 = 23{\cdot}4$ m.a.

$\therefore$ total current = 36·4 m.a.

Joint resistance of 3000^{ω} and $5400^{\omega} = 1929^{\omega}$

Total external resistance $= 3000 + 1929^{\omega}$

$= 4929^{\omega}$

$$\text{Number of cells required} = \frac{4929}{\frac{1{\cdot}82}{{\cdot}0364} - 4} = 108$$

With the secondary cells the calculation is even simpler.

Resistance in battery lead = 200

Total resistance = 4929 + 200 = 5129^{ω}

Current required = 36·4 m.a.

E.M.F. required = 5129 × ·0364 = 187 volts.

Type of Battery Employed.

The minimum power required is 100 volts secondary, or its equivalent in Bichromate, cells. The local battery is either a 3-cell Large Daniell or a 2-cell Bichromate.

CHAPTER XI

THE WHEATSTONE A.B.C. AND STELJES RECORDER

Introductory.

THE Wheatstone A.B.C., which is an example of step-by-step telegraphs, has been, and is still, very extensively employed upon minor circuits on account of the very small amount of skill required to work it. It possesses, however, the disadvantages of being both costly to provide and to maintain. In many cases it is being superseded by telephone circuits, but for the latter purpose two wires are required, instead of one, if the circuit is carried upon poles which have other lines upon them.

General Principle.

The electrical energy required for the operation of the instrument is obtained by revolving the handle of the sending instrument or "communicator" as it is termed. This operation causes the armature of a generator or magneto-electric machine to revolve and so generate an alternating E.M.F. The position of the key which is depressed determines the number of current waves sent out, and thus is made to control the position of the pointer at the distant end of the circuit.

A.B.C. Indicator.

The indicator bears a considerable resemblance to the P. O. standard relay in the general arrangement of its electrical and magnetic parts. Two soft iron armatures, rendered magnetic by induction from a curved permanent magnet of the horseshoe type, are placed between the four poles of the electromagnet. The axle carrying the arma-

tures also bears an arm upon which is pivoted an escape wheel of the form illustrated in Fig. 162. The movement of this arm is limited by the stop pins, P_1 and P_2 shown in Fig. 163. When an alternating current is passed through the coils of the instrument the arm oscillates

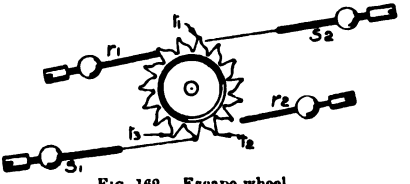

FIG. 162.—Escape wheel.

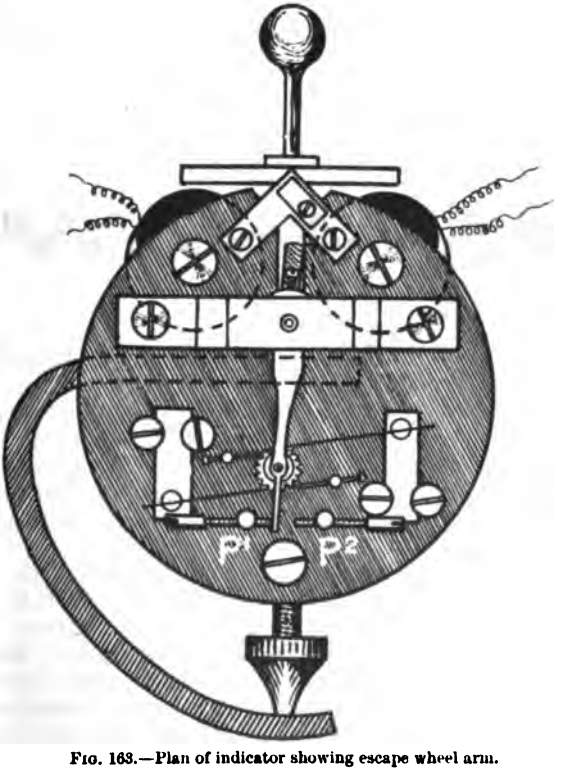

FIG. 163.—Plan of indicator showing escape wheel arm.

between P_1 and P_2 and, in so doing, causes the escape wheel to revolve. In Figs. 162 and 163 the arm is shown in its

left-hand position, so that a motion to the right therefore twists the escape wheel round to the extent of half a tooth. The tooth t_1, which is resting against the pallet spring s_2, remains stationary whilst the centre of the wheel moves over to the right. When this position is reached t_2 banks against the pin r_2 whilst s_1 has engaged with t_3. If the arm is now moved over to the left, the escape wheel again rotates in the same direction to the extent of half a tooth. It will therefore be seen that the escape wheel is rotated by the action of s_2 when the motion is from left to right and by s_1 when in the reverse direction. The function of the pins r_1 and r_2 is to prevent the wheel from moving more than half a tooth at a time when the arm moves from side to side.

The primary object of the stop pins P_1 and P_2 (Fig. 163) is to save the escapement wheel from the shocks which would result from its continual impacts upon r_1 and r_2.

FIG. 164.—Currents and letters.

It is, however, found that the increased wear due to this cause is very slight, and in some forms of apparatus P_1 and P_2 are omited (*vide* Fig. 165).

The 15 teeth of the escape wheel are slightly undercut to prevent the possibility of the pallet springs being jerked upwards by a sudden or "jerky" motion of the escape arm. In order to facilitate removal and adjustment these pallet springs are separately mounted upon removable brass blocks.

A complete revolution of the escape wheel needs thirty motions of the arm alternately right to left and left to right. These movements would be produced by sending fifteen complete alternations through the electromagnet. Each of the thirty positions of the escape wheel corresponds to a letter or character, and therefore the pointer, which is fixed to the escape wheel by means of a light steel axle, may be caused to stop opposite any pre-determined letter or character by sending the requisite number of alternate positive and negative currents through the instrument.

For example, the pointer will move from zero to *A* if one positive current is sent, whilst a positive followed by a negative current would cause it to move to *B*. If thirty currents of alternate direction were sent the pointer would make a complete revolution. The effect of each positive or negative current wave is clearly depicted in Fig. 164, but one example may perhaps be given. To send the word "ACE" the following currents would be required :—

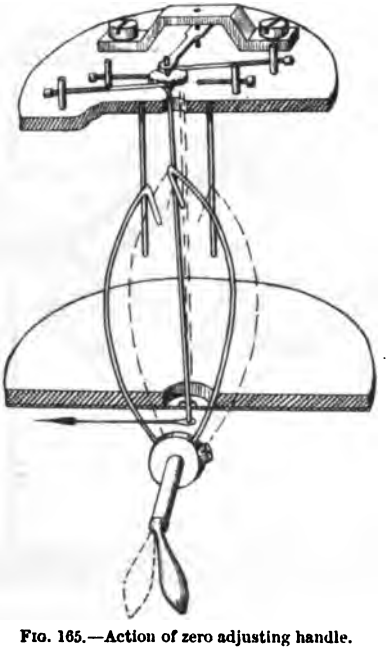

FIG. 165.—Action of zero adjusting handle.

Zero to *A* one positive
A to *C* one negative, one positive
C to *E* one negative, one positive
E to zero negative and positive alternately to the number of 13 negative and 12 positive.

In this way by suitably determining the number of alternate current impulses any word or combination may readily be signalled.

Before passing on to the communicator there are several details which should receive attention. It is essential that a mechanical method of putting the indicator pointer to zero should be provided, so that in the event of faults or interruption of a message by the receiving station both offices may re-set their pointers to zero. This is readily accomplished by the small handle (Fig. 165) at the base of the indicator dial, which mechanically moves the escape wheel

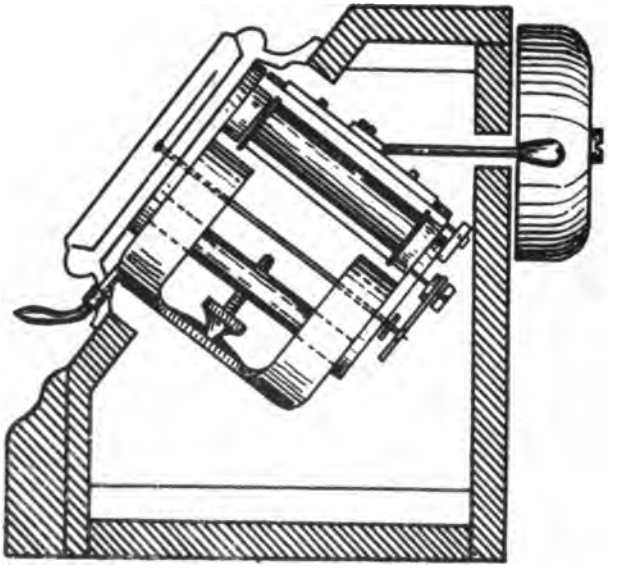

FIG. 166.—Combined indicator and bell, general arrangement of parts.

and pointer axle to right or left according to the direction in which the handle is moved.

CLOCKWORK BELL.

In the older forms of apparatus a clockwork bell is provided for indicating a call. The passage of a current through the electromagnet releases the mechanism and a revolving arm carrying two jointed hammers is rapidly

revolved. The hammers strike a bell in passing and so serve to attract attention. The arrangement is mechanically complex and is also costly. It has therefore been superseded by the magneto bell of the "combined indicator and bell."

Combined Indicator and Bell.

The combined indicator and bell is illustrated in Figs.

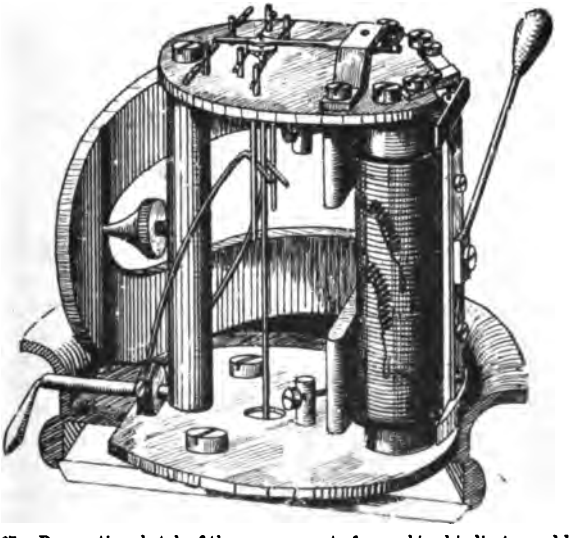

Fig. 167.—Perspective sketch of the arrangement of a combined indicator and bell.

166 and 167, from which it will be seen that the polepieces of the electromagnets are extended in an upward direction, and that above them are placed two soft iron armatures. These two armatures are mechanically connected to the light permanent bar magnet *NS*, which polarizes both. The two ends of the upper armature are South poles, and therefore the passage of a current through the instrument causes one end to be attracted whilst the other is repelled. When the current is reversed the armature moves in the opposite direction. Since the ends of the lower armature are of

opposite polarity to those of the upper one their tendency to motion is always in the same direction as that of the upper armature. Attached to the permanent magnet is an arm carrying a bell hammer normally resting upon one of the two bells between which it is placed. It will therefore be obvious that the alternating currents which actuate the indicator pointer will also cause the hammer to play between the two bells, thus giving a sufficiently loud ring to call attention to the circuit. A switch is provided which clamps the hammer of the bell when turned to the "off" position during the transmission of messages.

It may be remarked that comparatively frequent adjustment is required with combined indicator and magneto bell when the apparatus is heavily worked. This is particularly noticeable upon certain private wires rented from the Post Office.

The Generator.

It has previously been stated that an E.M.F. is generated whenever a conductor cuts a line of force. The value of this E.M.F. is directly proportional to the number of lines of force cutting a conductor in a given time. In order to generate any considerable value of E.M.F. it is necessary that a large number of lines of force should be cut at a considerable speed by a number of suitably arranged conductors. This result may be accomplished in quite a large variety of ways, but in the present volume it is only necessary to give a detailed explanation of one of them.

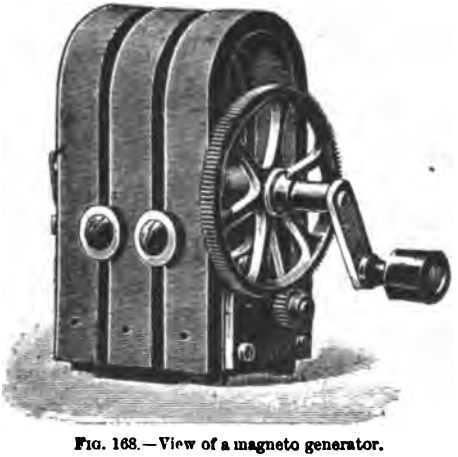

Fig. 168.—View of a magneto generator.

The type of machine chosen is that used so extensively in telephony under the title "generator," and also used in the Wheatstone A.B.C. and Steljes instruments. In reality, it is the Siemens magneto-electric machine of 1857, made to a small scale and minus the commutator.

The generator usually consists of three permanent magnets, whose poles of like sign are united by two hollowed soft iron pole-pieces, between which is placed a revolving armature of soft iron wound with a suitable number of turns of fine silk-covered copper wire. The instrument as a whole is illustrated in Fig. 168, whilst constructional sketches are given in Figs. 169 and 170. The armature is of the well-known H-form, and the coil is wound upon the central web. When the armature occupies the position shown in Fig. 169, the lines of force pass through the central web in the general direction shown by the two heavy lines. When the position of the armature is changed with respect

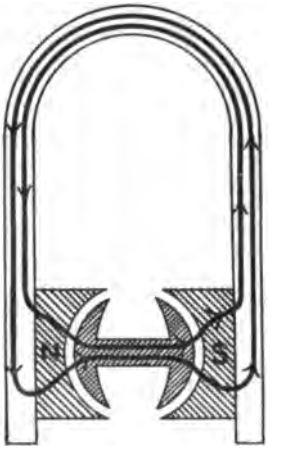

FIG. 169.—Magnetic circuit of generator.

FIG. 170.—Armature of generator.

to the magnet the position of the lines with respect to the coil of wire is altered, thereby generating an E.M.F. It should also be noted that the magnetic field passing

through the coil is intense, since the magnetic circuit is almost wholly of iron, the two small gaps of air between the armature and the polepieces being only of sufficient width to provide a working clearance.

It will now be well to consider a complete revolution of the armature, and in order that the various positions may be clearly realized, the value of the E.M.F. at every instant during a revolution, together with the position of the armature at each quarter of a revolution, is shown in Fig. 171. Imagine that the armature is revolving at a uniform speed, and that, to commence, it occupies the position marked "start." Here the whole of the lines of force pass through the curved portions of the armature, and none

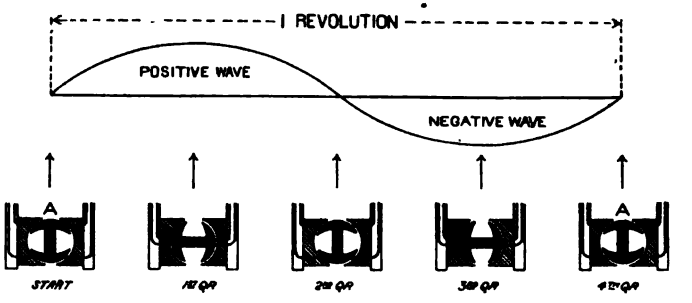

FIG. 171.—Illustrating current waves sent out by generator.

pass through the coil along the web. When the armature has turned through a quarter of a revolution the whole of the lines of force pass through the coil. At this point the value of the E.M.F. generated is at a maximum, whilst it steadily decreases in value during the succeeding quarter of a revolution. Up to the third quarter of a revolution the number of lines flowing through the coil in the opposite direction steadily increase in value until the maximum E.M.F. in the reverse direction is reached. From this point to the end of the revolution the value of the negative E.M.F. gradually sinks from the maximum value to zero, when the armature occupies the same position as at the start.

There are two forms of communicator in use, but their difference lies solely in the form of generator employed.

The older form has a large compound magnet with four coils of wire wound upon soft iron cores attached to the poles of the magnet. A soft iron armature is revolved in front of these coils by the handle of the communicator acting through a suitable gear (Fig. 172). The motion of the armature alters the number of lines of force passing through the cores, and E.M.F.s are consequently generated. After the detailed discussion of the generator form the details should be obvious.

The Communicator.

It has been shown how the pointer may be caused to travel to any one of the thirty characters by meting out a suitable number of current impulses alternately varying in

Fig. 172.—Principle of the old form of communicator.

direction. It is now necessary to consider the mechanism of the communicator by which this object is effected.

The dial, furnished with a pointer, is divided into thirty divisions corresponding with those of the indicator. A key is placed opposite each character, and messages are sent by revolving the handle and depressing the keys in the order in which the letters occur in the words to be signalled. The completion of a word is indicated by pausing at zero. The pointer is arrested at the point where the key is depressed, and is released immediately a second key is put down. This depression of the second key also restores the first to the normal position.

Arrangement of the Keys and Endless Chain.

The necessity for pivoting the keys is avoided by an arrangement which will readily be apprehended from a

consideration of Fig. 173. The lower end of each key passes through a radial slot in the key plate. The upper end, carrying the finger-plate K, projects above the slot, and is kept in position by the circular brass ring B, which is screwed down above all the keys. Since the fitting at the angle is made rather loose the key is able to rock, thus producing the effect of a hinged joint in a singularly neat manner.

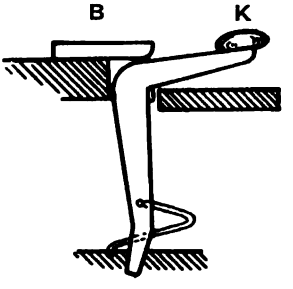

FIG. 173.—Key.

The lower ends of all the keys rest upon an endless chain which is carried upon a series of pulleys (Fig. 174). The length of the chain is such that one key only may be depressed at any one time. The depression of a second key tightens the chain at the point where the first key is depressed, so thrusting the first back to the normal position. In order to provide a margin of adjustment two extra pulleys

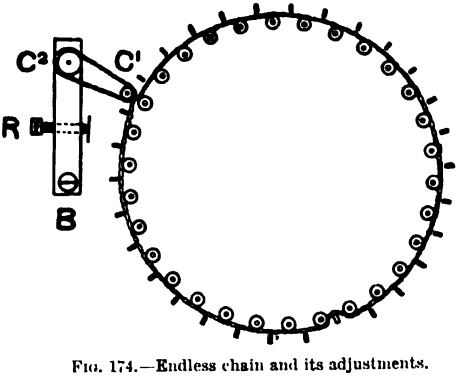

FIG. 174.—Endless chain and its adjustments.

C_1 and C_2 are employed, so that by turning the screw R, which is fixed upon the brass block movable at B, the requisite tightening or slackening of the chain may readily be effected.

Operation of Contact Maker and Pawl Arm.

The exact connection between the number of currents sent out, the pointer, and the armature of the generator remain to be dealt with. In Fig. 175, some liberties have been taken with the actual details of the construction of the instrument, and it is especially desired that this fact should be borne in mind. The main axle to which the handle is attached is correctly shown, but the remainder of the apparatus has been turned through an angle of 90°.

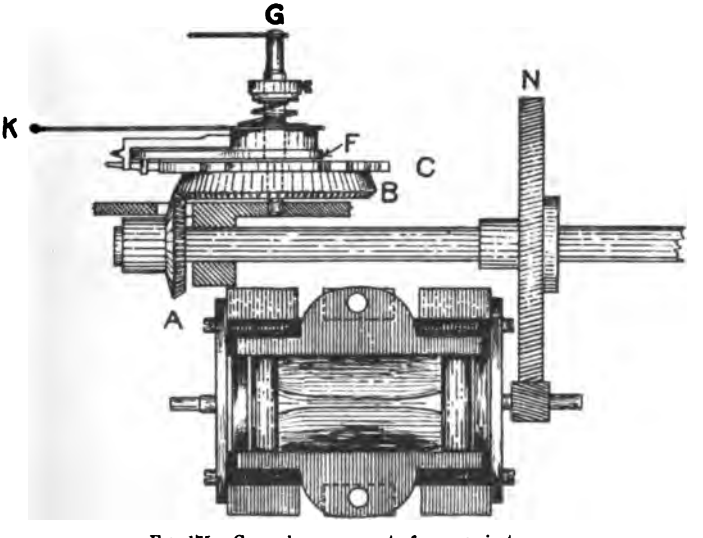

Fig. 175.—General arrangement of communicator.

The handle carries the armature driving wheel *N* and the bevel wheel *A*, which causes the corresponding wheel *B* with the spur wheel *C* to continuously revolve. Above this is an arm fitted with a pawl which engages the spur wheel and so imparts motion to the pointer carried upon the axle *G*. Between *F* and the pawl a friction-tight contact arm *K* is fitted. This arm tends to revolve with the escape wheel, but is prevented from doing so by a stop pin.

Referring now to Fig. 176, which gives a plan of the important parts of the spur wheel, etc., it will be seen

that when all the keys are raised the pawl engages with one of the teeth upon the spur wheel, and so causes the arm M to revolve. The contact arm K is fixed friction-tight with the pawl arm M and therefore, whilst M revolves, K moves upwards, thus establishing a connection between the pivoted lever T and the uninsulated side of the contact arm K, and breaking that which normally exists between T and S. Since 15 complete alternations must be sent out during one revolution of the pointer the armature of

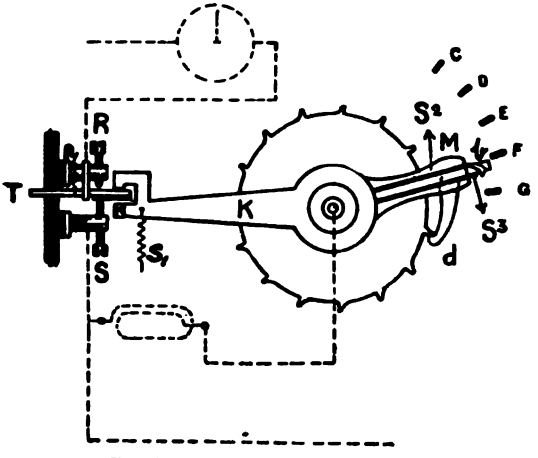

FIG. 176.– Spur wheel and contact maker.

the generator must make 15 revolutions whilst the pointer makes one.

The function of the spur wheel and pawl is to mechanically disconnect the handle from the pointer immediately the latter reaches a depressed key. The contact arm then electrically disconnects the armature, so preventing more than the correct number of alternations from being sent out. Immediately the extremity of the pawl b meets a depressed key, d moves outwards, thus disconnecting M from the spur wheel. The spring S_1 upon the contact arm immediately restores the contacts to their normal position. If the zero key were depressed M would stop opposite zero whilst the spur wheel continued to rotate. The depression of, say, the A key and the consequent rising of the zero

key would permit the springs S_2 and S_3 to restore the pawl to its normal position, when it would again engage with the spur wheel and move forward to A. In doing this K would move with M, so joining up the armature. Immediately M reached A the pawl would again disengage, and K would restore the contacts to the normal, so disconnecting the armature. If the D key were now depressed the pawl arm M would move from A to D, during which time K would join up the armature.

The escape wheel is provided with 15 teeth, and is permanently geared to the armature. The distance between

FIG. 177.—View of A.B.C. set.

each tooth therefore corresponds to one complete revolution of the armature. It is essential that the armature should always be in the correct position with respect to the pole-pieces when the contact arm K joins it up. Were this not assured two positive or two negative currents might be sent out as the last current to signal a particular letter, and the first current for the next letter. The spur wheel and pawl provide that the armature is in exactly the same position when again connected to line as it was when the last current was sent.

It may be stated that upon circuits with more than two offices the necessity for attending to the instrument whenever the needle moves is obviated by the use of a system of calling, in which the various calling signals are recognizable by sound.

Connections of A.B.C. Sets (Ordinary or Series Working).

The communicator and indicator are usually placed in series. When the communicator is at rest the indicator is connected between line and earth, or between the up and down lines by the contact arm.

A view of the A.B.C. apparatus (clock-work bell) as a whole is given in Fig. 177.

The connections of two A.B.C. sets upon one circuit are depicted in Fig. 178, the down set having a communicator, indicator, and bell of the old type, whilst at the up station

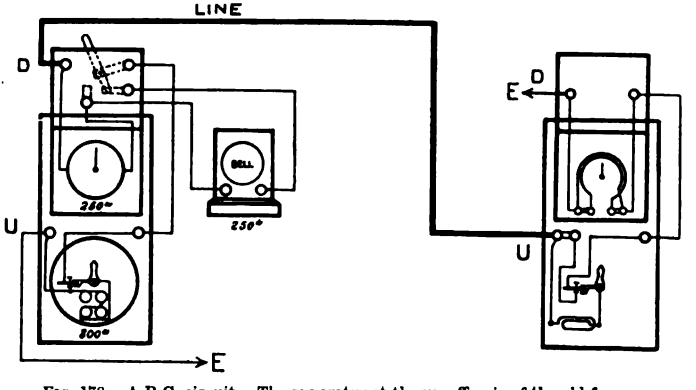

Fig. 178.—A.B.C. circuit. The apparatus at the up office is of the old form.

is shown the new form of communicator and the combined indicator and bell. The path of the current is sufficiently obvious.

Leak-Working.

In the case of three or more offices upon one circuit considerable advantage is derived by working the instruments in parallel, or as it is termed "leak-working." The coils of the indicators when placed in series upon a circuit represent a very considerable amount of self-inductance which necessarily reduces the value of the effective current passing through the circuit, and it is to this effect that leak-working owes its inception.

The communicators employed for this purpose are invariably of the generator form, provided with three terminals. The connections of three stations upon one circuit are shown in Fig. 179. The inner left-hand terminal of the communicator is left disconnected, the coils of the indicator being placed in series (resistance 1000$^{\omega}$). The generator shares its current with the whole of the indicators in parallel, and it will also be noted that the communicator is disconnected when not actually sending out a current.

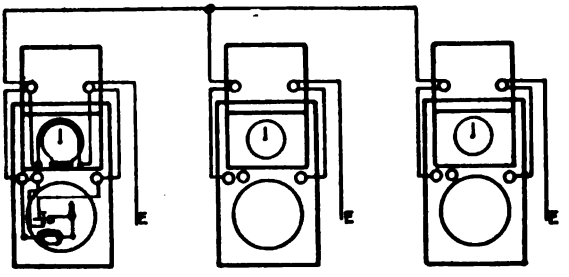

FIG. 179.—Leak working.

THE STELJES RECORDER.

GENERAL PRINCIPLE.

The Steljes typewriting telegraph system consists in replacing the indicator of the ordinary Wheatstone A.B.C. by a recorder which prints the messages upon a tape in Roman characters. The system is not used upon public telegraph circuits, but its employment upon private lines rented from the Department is very extensive. The advantages of a record of the actual message transmitted is so obvious as to require no argument.

The position of the type wheel is determined by the number of currents sent out, in a similar way to that in which the movement of the A.B.C. indicator needle is controlled. The printing electromagnet is placed in series with the escapement electromagnet, the armature of the

latter being permanently attracted whilst the pointer of the communicator is in motion. It is only released when the series of currents is ended. The moment the current ceases the tape is brought into contact with the inked type wheel, the character thereby recorded, and the tape moved forward. The type wheel is inked by means of a light wheel which normally rests upon and revolves with it.

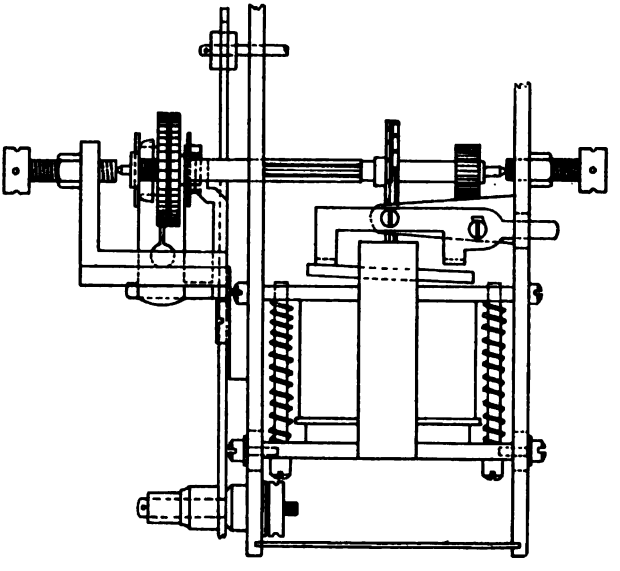

FIG. 180.—Escapement electromagnet.

TYPE WHEEL ESCAPEMENT.

The escapement electromagnet with its polarized armature is of the form which has long been familiar in telephone magneto bells. Its permanent magnet curves round from the yoke of the electromagnet to the centre of the soft iron armature, so making the two ends of like polarity. In fact the arrangement is very similar to that of the A.B.C. combined indicator and bell, but only one armature instead of two is employed. The pallet (Figs. 180 and 184) which engages with the escape wheels is fixed at

right angles to this armature. Each wheel has 15 equally spaced teeth placed so that the apices of the teeth of the one wheel are opposite the bases of the teeth of the other. The escape wheels are placed upon the same axle as the type wheel, which revolves when released by the pallet. When the armature moves, the pallet releases the tooth with which it is engaged, and thus allows the axle to turn until it engages with the tooth of the other escape wheel, *i. e.* the axle moves one-thirtieth of a revolution. In order therefore to bring any letter upon the type wheel directly above the paper, it is only necessary to send the requisite number of alternations through the electromagnet. This is of course accomplished by the communicator, and it is

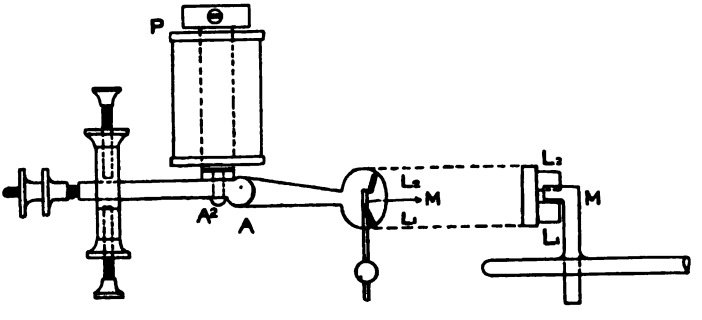

FIG. 181.—Printing electromagnet, showing armature attracted.

therefore clear that the type wheel will take up a position in conformity with the key which is depressed.

PRINTING ARRANGEMENTS.

The printing mechanism is operated by a somewhat heavier weight than that required for the escapement. The principle of the device will readily be apprehended from Fig. 181.

The armature A_2 of the electromagnet P is pivoted at A, so that when attracted the right-hand side of the lever is depressed and the left side raised. Normally, the underside of M rests upon the projection L_1, but immediately the armature is attracted L_1 is depressed, and M moves forward until caught by L_2, which is of course depressed.

Immediately the armature is released by the cessation of the series of currents M revolves, and is again caught by L_1. The axle carrying M also bears an eccentric, the revolution of which raises the paper against the type wheel, thus printing the letter immediately above the paper (compare Figs. 181 and 184).

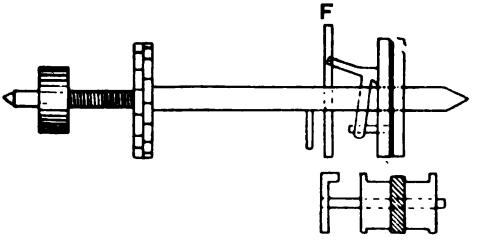

FIG. 182.—Type wheel in position for printing letters.

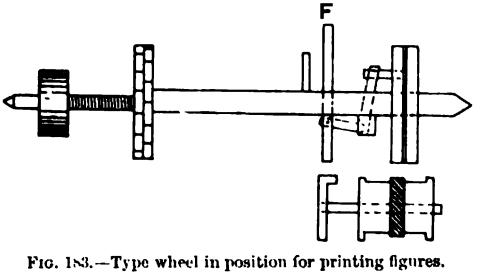

FIG. 183.—Type wheel in position for printing figures.

FIGURE CHANGING CAM.

Two type wheels mounted side by side upon the same axle are employed, the one bearing letters and the other figures and various other useful signs. The wheels are capable of lateral motion and either may be brought directly over the tape according to the position of the "figure changing cam." Two divisions exactly opposite to each other upon the communicator are marked respectively "letters" and "figures." At the corresponding points upon the type wheels blanks are left. When the printing lever raises the tape up to the type wheel at these positions no character is printed, but the radial pin F is struck, so

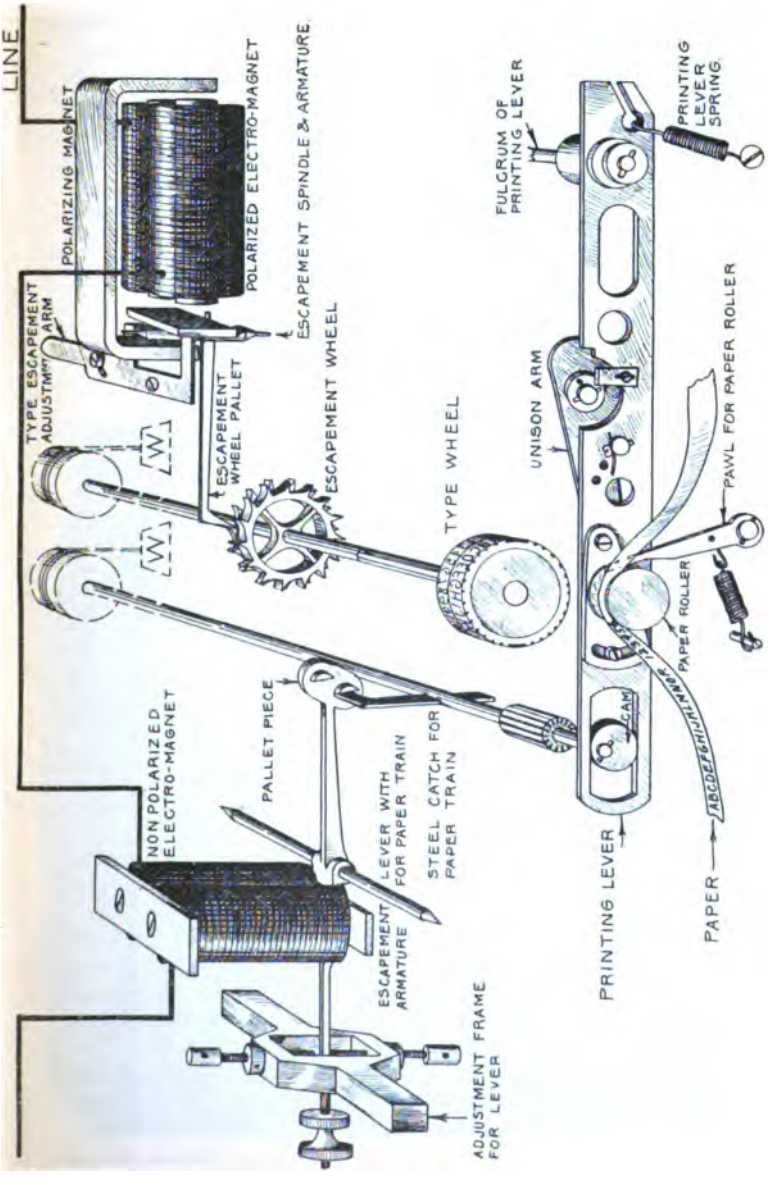

FIG. 184.—General figure illustrating principle and essential parts of recorder.

moving the type wheels along the axle. In Fig. 182 the letter wheel is above the printing space upon the tape whilst in Fig. 183 the figure wheel is similarly placed. When the upper end of *F* (Fig. 183) comes to its lowest position the raising of the printing lever in response to the depression of the "figures" key causes the wheels to take up the position shown in Fig. 182. The change from figures to letters is made in a similar way, half a revolution (15 letters) of the communicator later. The type wheel

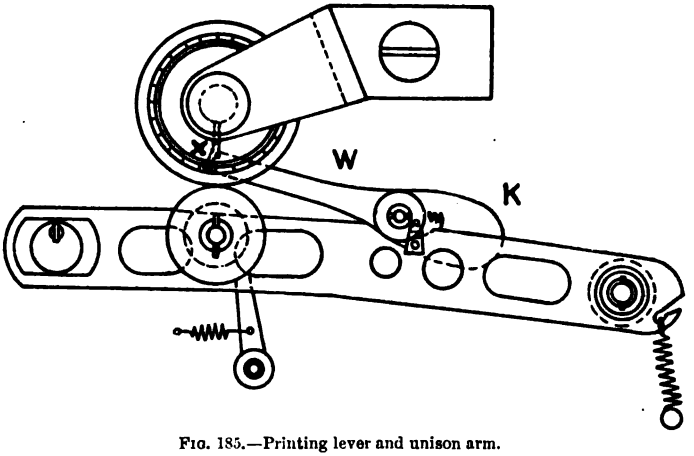

FIG. 185.—Printing lever and unison arm.

which is not in use strikes upon a light forked steel spring which covers the two outer thirds of the paper.

GENERAL ARRANGEMENT AND SLIP FEEDING DEVICE.

The remaining details of the arrangement will be best apprehended by means of the conventional diagram given in Fig. 184. Every time the printing lever is moved up against the type wheel the cam engages a lower tooth upon the ratchet wheel, and the descent of the lever therefore feeds the slip forward to an extent equal to the space of one letter, so placing it in position for the printing of the next letter.

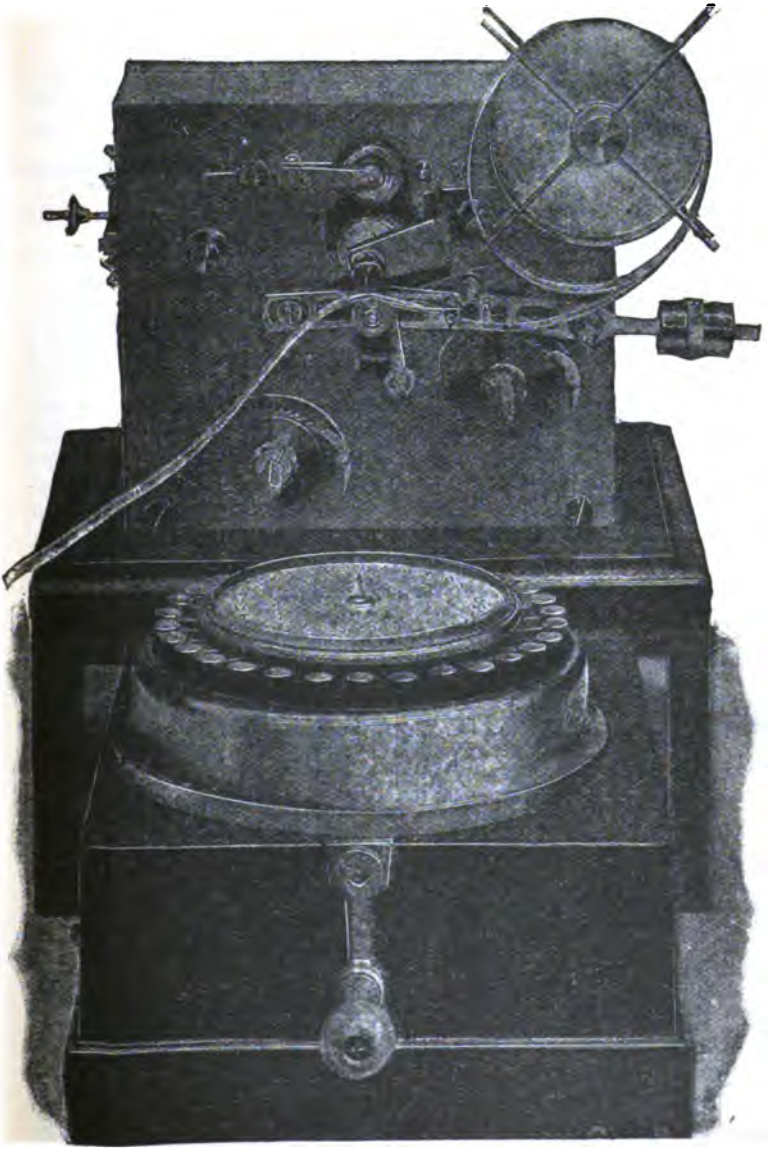

FIG. 186.—General view of Steljes apparatus. (In later instruments the counter weight upon the printing lever is replaced by a spring as shown in Figs. 184 and 185.)

Synchronizing Lever.

The synchronizing device is exceptionally simple and effective. Upon the type wheel axle a radial arm X (Fig. 185) projects which engages with the end of the lever W when in

OVER A 50 KM. FIELD TELEGRAPH LINE

Fig. 187.—Specimen of printed message.

its upper position. The lower part of the lever carries a pin W_1 which is struck by the printing lever every time a letter is printed, thus depressing the lever W. This lever is fixed friction-tight upon an axle which tends to move it to its highest position when the type wheel has moved through about three revolutions. If therefore the pointer of the communicator is allowed to make three complete revolutions without printing a letter the radial arm X is arrested and the type wheels stopped at zero. Immediately the type wheel stops the zero key is depressed and the communicator and the type wheels are therefore at zero,

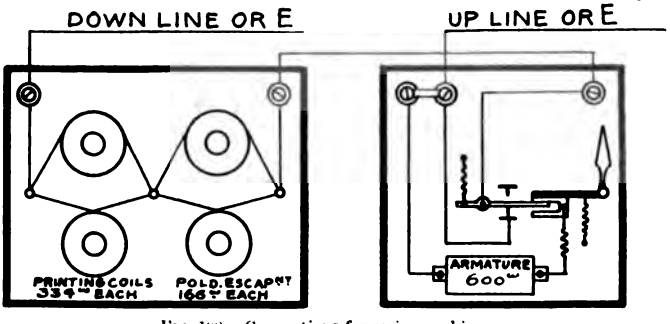

Fig. 188.—Connections for series working.

but the printing lever rises and puts the lever W back to its lower position as shown in Fig. 184. Both instruments are therefore at zero and the message may at once be signalled.

The general appearance of the apparatus is shown in Fig. 186, and a reproduction of a part of a message trans-

mitted over a 50-kilometre field telegraph line established in Spain during manœuvres is shown in Fig. 187.

The Typewriting Telegraph Corporation who control the Steljes patents have also produced a motor driven communicator of considerable power—in fact as many as one hundred recorders have been simultaneously worked from it.

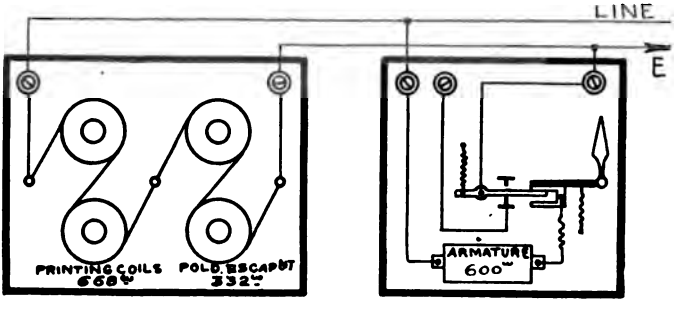

FIG. 189.—Connections for leak working.

CONNECTIONS.

For ordinary, or series, working the recorder coils are joined up so as to give a resistance of 500Ω and the set as a whole is connected to line and earth in similar fashion to an ordinary A.B.C. set. When leak working is desired the windings of the coils are placed in series and a resistance of 1000Ω is thereby obtained. The conditions will, however, be evident from consideration of Figs. 188 and 189.

CHAPTER XII

THE HUGHES.

Introductory.

THE Hughes system, which may be classed under the heading of synchronous type-printing telegraphs, is largely mechanical in action and differs from all other systems in two most important particulars :—firstly, a single current only is required for each letter or character printed, and secondly, the type wheel revolves continuously and is not checked or stopped whilst a sign is being printed. The working currents are of equal duration, but are separated by unequal intervals of time.

Upon a cable circuit having a working speed of 40 words per minute with the Wheatstone apparatus and shunted condenser system, the Hughes may be worked at the highest speed at which it can be manipulated. The speed at which the instrument can be operated is also considerably in advance of the sounder, and in France the Hughes is employed in every case in which Morse working will not suffice to dispose of the traffic and in which high-speed working is not justified. In the British Post Office it is almost exclusively employed upon continental lines, where the gain in the working speed of the circuit amply justifies the costly apparatus and its somewhat expensive maintenance.

The general appearance of the apparatus and the disposition of its parts are illustrated in Figs. 190 and 191.

General Principle.

The type wheel at one end of the circuit is exactly similar to that at the other end, revolving in complete synchronism, *i. e.* they not only revolve at precisely the

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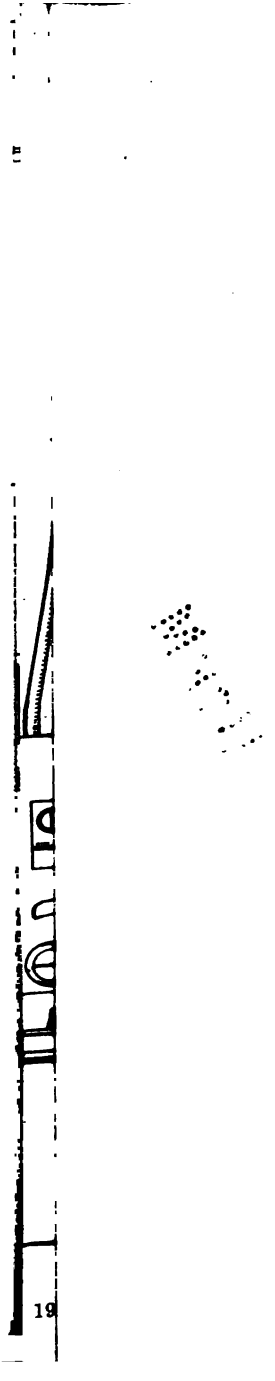

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same rate, but at any instant the same letter or sign upon each wheel occupies a position immediately above the tape. If at this moment the tapes at both ends are brought into contact with the type wheels the same sign will be printed at each end. The type wheel is inked by the inking wheel, which presses lightly upon it.

The transmitting portion of the apparatus consists of a keyboard furnished with 28 keys (see Fig. 190). Each of these keys is mechanically connected to a pin working in a radial slot in a circular plate. The chariot, which consists of a radial arm carrying a pivoted lever in connection with the stationary contact lever, sweeps over the pins. When a key is depressed the corresponding pin is raised and the end of the pivoted lever moves upwards when the chariot passes over it. This causes a current to be sent out to line. The home instrument is also actuated at the same instant by a projection upon the contact lever which raises the armature from the coils.

It will therefore be seen that a current may be sent out at any one of the 28 points in accordance with the position of the key which is depressed. It may, however, be pointed out that one, two, three, or even four currents may be sent out during one revolution of the chariot. This is, however, considered fully later.

The chariot and the type wheel are connected and revolve at precisely the same speed. Therefore each position of the chariot corresponds to the same position upon the type wheel. If the key marked "*R*" is depressed the letter "*R*" upon the type wheel will be immediately above the tape at the instant when the chariot is above the raised pin connected to the "*R*" key. As the pin is raised the chariot sends a short current out to line and at the same time mechanically operates the home apparatus. The result is that the letter *R* is printed at both stations.

The whole of the movements are controlled by three main axles which may be respectively designated the printing, the type wheel, and the chariot axles. The printing and type wheel axles are horizontal and parallel, whilst that of the chariot is vertical and is driven by means of an equal bevel wheel upon the type wheel axle.

The sole function of the current is to release the armature of the electromagnet, and this motion is made to link up the

printing, driving and the printing axle proper for a single revolution. By mechanical devices the revolution of the printing axle effects :—

1. The synchronizing correction.
2. The printing of the character.
3. The progression of the paper.
4. The replacement of the armature.

Each current received or sent out brings about a complete revolution of the printing axle, which runs at seven times the speed of the type wheel and chariot. At the instant when the letter is printed the face of the particular type should be exactly parallel with the paper. Now, by means of a cam upon the printing axle, the position of the type wheel is adjusted every time a letter is printed. Since at least one and sometimes three or four characters are recorded during each revolution the frequency of this mechanical correction is more than sufficient to ensure absolute synchronism between the two instruments. An electro motor controlled by a rheostat provides the motive power for rotating the mechanism whilst a suitable governor determines the speed at which it runs. As will be seen later, it is by means of this governor that the speed of the instrument is adjusted to be in unison with the apparatus at the distant end. The functions named under 2, 3, and 4 require no explanation.

Having dealt with the general principle of the instrument, it will now be necessary to consider the details of the mechanism. These will not, however, prove very intelligible unless the reader has grasped the fundamental principles which have just been stated.

The Hughes Electromagnet.

Two coils of wire are wound upon the soft iron cores attached to the poles of a powerful compound magnet (Fig. 192). The armature, which is also of soft iron, is normally attracted to the cores, but this attraction is opposed by two antagonistic springs. The armature is, however, held down by the downward attraction of the magnet which is greater than the upward pull of the springs. If, for the sake of illustration, the force of attrac-

tion is 100 units and the upward pull of the spring is 92, the armature is held down by a force equal to 8 units. The passage of a current through the coils in such a direction as to oppose the magnetism of the cores will cause the armature to be released immediately the attraction is reduced below 92 units. The armature will then fly off with the full force of the spring, *i. e.* with a force of 92 units. In this way the reduction of the attraction by any-

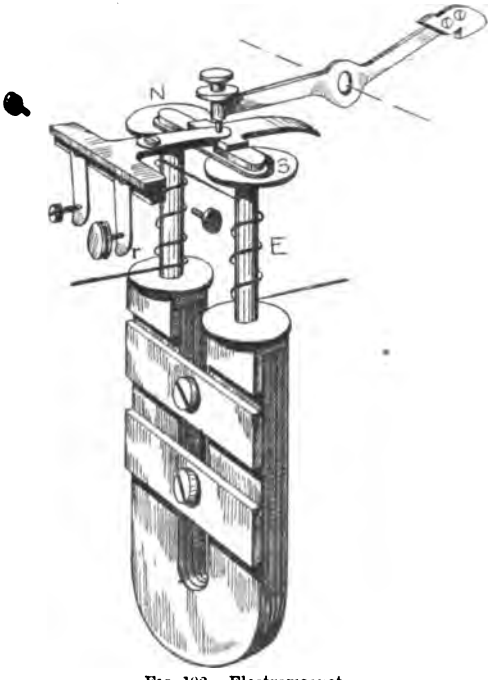


FIG. 192.—Electromagnet.

thing over 8 units brings into play the full force of the spring. The upward movement of the armature serves to bring into operation the various mechanical portions of the apparatus which synchronize the two type wheels, print the letter, move the paper forward, and replace the armature. The Hughes is therefore a directly, and not a relay, worked instrument.

The value of the attraction between the cores and the armature may be varied by sliding the soft iron bar to right or left as required. The bar (Fig. 193) forms a conducting path for the lines of force, thus reducing the number flowing through the armature, and hence the force of the attraction. When the lever is pushed well over to the right it is evident that the attraction will be least, whilst it will be gradually increased as the volume of that part of the soft iron bar resting upon the right-hand magnet limb is reduced by sliding it to the left.

The upward pull of the armature is produced by two springs acting upon the axle of the armature lever. One spring is of considerable strength, and very rarely requires

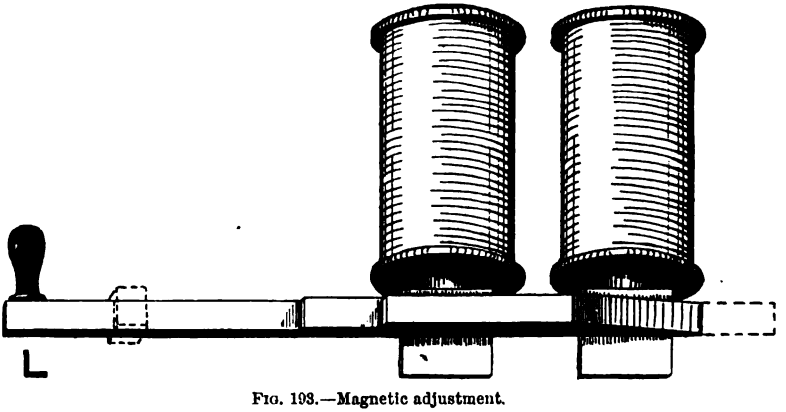


FIG. 193.—Magnetic adjustment.

adjustment. The second spring is of a much lighter description, and is provided with a thumb-screw. This screw is first of all placed in such a position that its thread extends equally upon either side of its support, thus providing an equal range of adjustment in each direction. The permanent magnet armature is then adjusted until the slightest vibration will serve to release the armature. The adjusting screw is then given two turns in such a direction as to reduce the force tending to raise the armature. This provides ample working margin without unduly decreasing the sensitiveness of the instrument.

The coils are differentially wound, and have a resistance of 500$^{\omega}$ each, or 1000$^{\omega}$ in series.

It should also be pointed out that the position of the electromagnet is adjustable, so as to ensure that the armature shall lie evenly upon the centre of the polar projections.

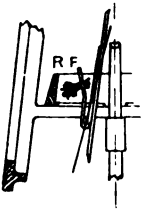


FIG. 195.—Brake on the governor.

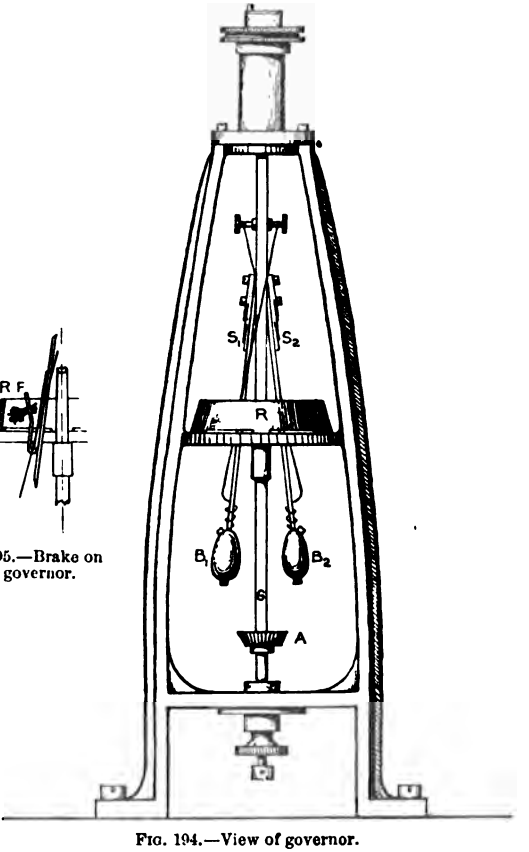


FIG. 194.—View of governor.

A piece of slip is placed between the armature and the cores, and is secured in position by suitable clips, to prevent "sticking" and to render the action more rapid.

Motive Power and Governor.

The latest form of Hughes instrument is driven by an electromotor worked from the telegraph secondary cell installation, so avoiding the use of the weight which had to be periodically raised. In order to obtain perfect uniformity of speed the back end of the motor axle is furnished with a bevel wheel which gears into a similar wheel A upon the vertical axle G of the governor (Fig. 194). As the axle rotates the two bosses B_1 and B_2 fly outwards, but this motion is opposed by the springs. Referring now to Fig. 195, it will be seen that the tow brush or brake upon each rod comes into contact with the inner side of the ring R.

If the speed tends to suddenly increase, the bosses B_1 and B_2 increase the pressure of the brush upon the ring, and a very considerable increase of energy is therefore needed to produce a small increase of speed. In the same way a decrease in the speed reduces the pressure between the ring and the tow brushes, so that less energy is required to drive them round. This action secures the provision of the extra energy required when the printing axle is operated, and besides prevents the instrument from increasing its speed during the intervals of inaction. In this way the speed is maintained at a remarkably constant and uniform value.

The general speed of the apparatus depends upon that of the motor, which is regulated by introducing or withdrawing resistance placed in series with it. For this purpose a 100-ohm slide rheostat is provided.

The final adjustment is, however, made by turning the milled head at the top of the governor, which raises or lowers the bosses upon the rods carrying them. In this way the "braking" effect may be varied to a nicety.

Earthing of the Line immediately the Armature Rises.

In order to obtain the maximum sensitiveness it is essential that the current shall only rise to a value sufficient to release the armature. The passage of a large current would produce trouble due to residual magnetism, as the opposing magnetizing force exerted by the current would not totally

disappear. In that case, to keep the armature upon the cores when replaced, the adjustment would have to be of an extremely coarse character.

When the armature *a* rises and comes into contact with the lever (Fig. 196) the line is earthed, thus short-circuiting the coils of the electromagnet. The path of the current is first of all through the contact lever, through the stud *K* and the spring *S*, and so through the coils to earth. The armature *a* rises and strikes sharply against the lever. Immediately this contact is made, the line path of the current is through the contact lever *c* viâ *a* to earth.

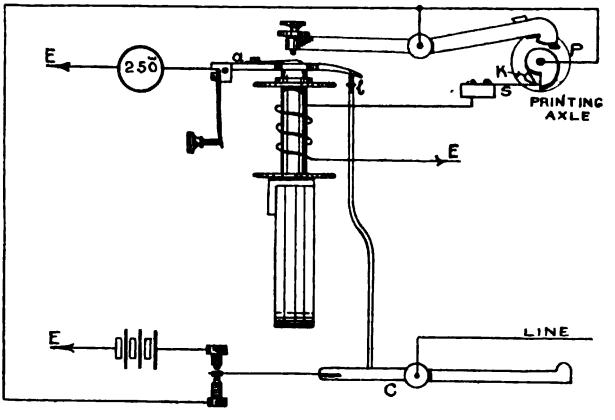


FIG. 196.—Skeleton connections and arrangement of Hughes apparatus.

The connection of the line direct to earth immediately the instrument has been actuated greatly facilitates the discharge of any charge or current remaining upon the line, and therefore increases the length of the line over which the system can be worked.

ELECTROMAGNET DISCONNECTED WHILST THE ARMATURE IS REPLACED.

The electromagnet circuit is broken whilst the armature is replaced upon the cores in order to avoid ill-effects from the E.M.F. of self-induction which is thereby generated. This induced E.M.F. is in the same direction as the current

which caused the armature to rise. Since the electromagnet circuit is open there is no path for the E.M.F. to act through, and consequently no effect is produced. Were a path existing the armature would fly off the cores, due to the demagnetizing force of the self-induction discharge.

Whenever a letter is printed the cam P upon the printing axle makes a complete revolution. It carries with it the pin k, thus breaking the contact existing between K and the spring S. This disconnects the electromagnet until the cam K has resumed its normal position. But the cam P has, during the earlier part of its revolution, replaced the armature upon the cores by its action upon the lever l. It will therefore be seen that the electromagnet circuit is open during the time the armature is being replaced.

Keyboard.

From inspection of Fig. 190 it will be seen that the instrument is provided with 28 keys arranged somewhat after the fashion of a piano keyboard. The shorter black keys are raised above and alternate with the white ones. The first and sixth white keys are blank, whilst each of the remaining keys bears two characters. These two blank keys are employed for the change-over from letters to figures, or *vice versa*, and are known as the "letter blank" and "figure blank" keys respectively.

The Chariot.

Twenty-eight letter pins, which may be raised by their respective keys, normally rest within the radial slots upon the circular plate shown in plan in Fig. 199. These pins are of the form depicted in Fig. 197, and are normally held in position by the spiral springs attached to them. The depression of a key raises the relative pin above the pin plate, as indicated by the dotted outline at M.

The chariot revolves with the type wheel axle to which it is geared by equal bevel wheels and maintained in intimate contact by the upward pressure of the spiral spring S (in compression). The chariot axle A carries a radial arm C upon the end of which the rocking lever D is pivoted. The outer end of this lever is directly above the pins in the key plate, whilst the inner end is connected to the lipped

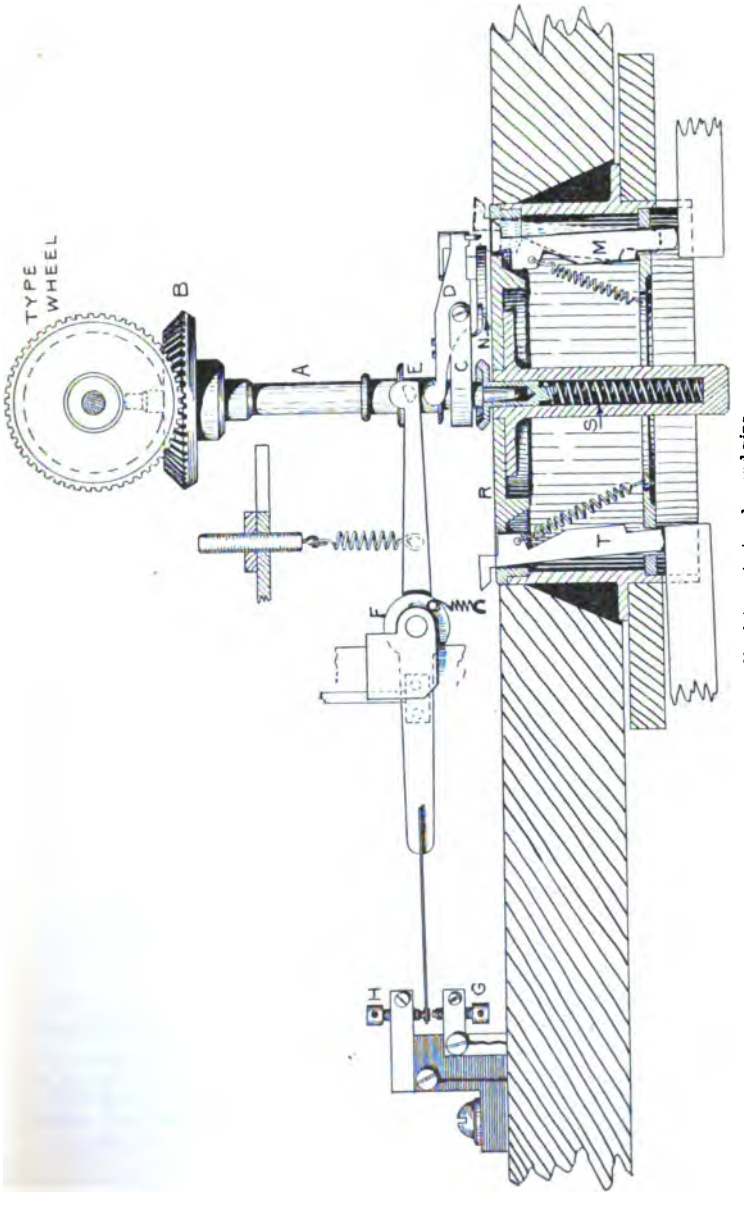


FIG. 197.—Chariot, contact maker and pins.

steel collar *E* fixed quite loosely upon the chariot axle *A*. The inner end of the pivoted contact lever *F* carries a projection resting upon the under-side of the upper lip of the steel collar. The outer end normally rests upon the contact stud *G*, but clear of *H*.

The chariot sweeps round above the pins, and when it meets a raised pin the inner end of the rocking lever *D* is depressed, so pulling down the collar *E* which raises the end of the contact lever from the stud *G* to *H*. As *H* is in connection with the battery and the contact lever is to line a current is sent out during the time that the chariot is passing over the pin. The adjustments of these contacts and slots are quite obvious and should need no further comment.

The Rejector.

When any particular key is depressed the letter or character it represents is only printed once, no matter how long the key is kept down.* Moreover it is impossible to release a pin whilst the chariot is actually passing over it, thus ensuring that every current sent out shall be of precisely equal duration — a matter of very considerable importance. These results are obtained by the "rejector," so called on account of its action in rejecting a pin over which it has passed once without the key being released. It is carried upon the arm of the chariot and consists of a steel plate *N* of the shape illustrated in Fig. 198. In order to prevent the breakage

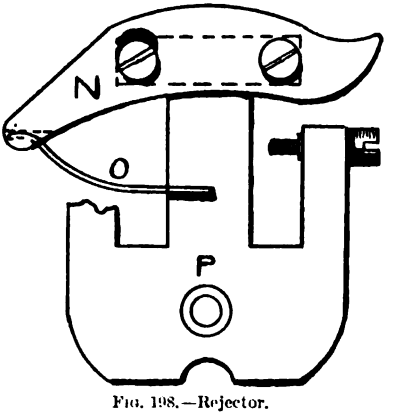


Fig. 198.—Rejector.

* This statement is not strictly true in practice, since a letter may be duplicated by depressing key too lightly (see page 393). By forcing a piece of cardboard between the letters *G* and *U* a continual call is given to the distant station, currents being transmitted every time the chariot passes the pins.

of any pin which happens to stick the forward portion of the plate is secured by a screw passing through a slot against the inner end of which it is normally held by the spring *O*. This gives the plate a certain amount of play.

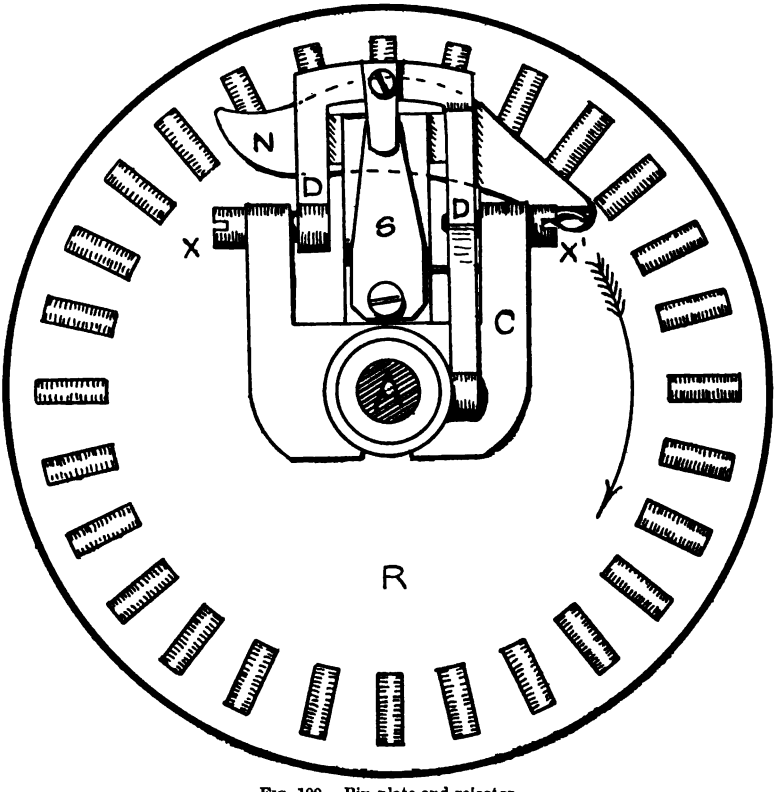


FIG. 199.—Pin plate and rejector.

Referring now to Fig. 197, which has been lettered to accord with Figs. 198 and 199, it will be seen that the forked chariot arm *C* carries the contact arm *D*, beneath which is the rejector. Immediately the forward portion of the rejector meets a raised pin, that pin is held until the rejector has passed it, during which time the release of the

key in connection with it does not permit the pin to fall back. When the back end of the rejector has passed the pin, it is already pushed back beyond the reach of the contact arm, and therefore when the chariot next passes a second current is not sent out. The letter may, of course, be printed twice if the key is released immediately the chariot has passed and is then depressed again before the rejector reaches the pin.

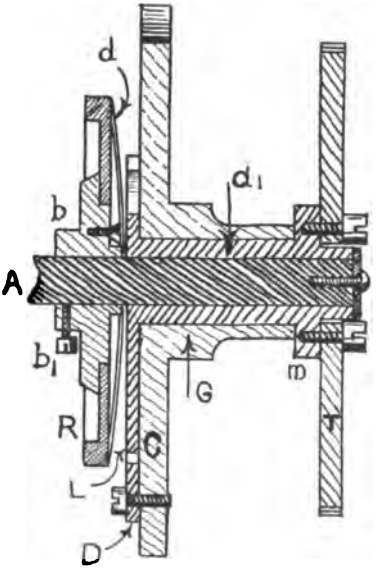


FIG. 200.—Type wheel axle.

NUMBER OF CHARACTERS WHICH CAN BE PRINTED PER REVOLUTION.

The mechanical inertia limits the number of characters which can be printed during a single revolution of the type wheel. After the depression of the letter blank key, the next letter which can be printed is *E*, followed by *J*, *O*, and *T*, *i.e.* every fifth letter. The chariot, however, covers three pins only in order to provide a working margin.

The Type Wheel Axle.

The type wheel axle is driven by the motor and transmits the motion to the chariot by means of bevel wheels. It carries three wheels, (1) the type wheel, (2) the correction wheel, and (3) the ratchet wheel. The ratchet wheel *R* (Figs. 200 and 201) is held in contact with the collet upon which it is mounted by the dished disc *d*. The collet is secured to the axle by the screw b_1, but the ratchet wheel

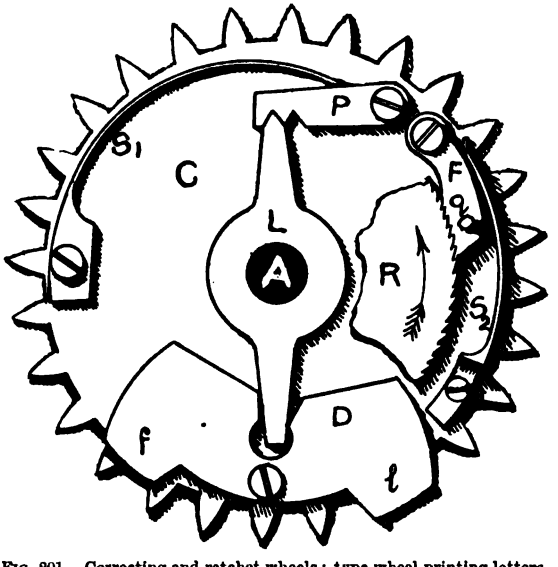


Fig. 201.—Correcting and ratchet wheels; type wheel printing letters.

is only friction-tight upon it, and may therefore be held stationary whilst the axle continues to revolve. The ratchet wheel (Fig. 201) is engaged by the pawl *F* fixed to the face of the correcting wheel *C*. By means of the pawl *P* the motion of the correcting wheel is transmitted through the lever *L* to the tube d_1 which is rigidly connected to the type wheel *T* (Fig. 200). This tube passes over the type wheel axle, but is sufficiently loose upon it to prevent the motion of the axle being communicated. Now the correcting

wheel is carried upon a second tube which fits loosely over the type-wheel tube. It will therefore be seen that:—

1. If the correcting wheel is held the type wheel axle may continue to revolve, whilst the ratchet, correcting, and type wheels, are stationary.

2. Since the ratchet wheel drives the type wheel through the pawl upon the correcting wheel and the lever upon the type wheel tube, the type wheel may be displaced with respect to the correcting wheel to an extent which is limited by the two positions which the lever may occupy upon the pawl. The correcting and type wheels can only be moved $\frac{1}{56}$ of a revolution with respect to each other.

3. The relative position of the ratchet wheel and that of the type wheel and correcting wheels can be varied to any extent.

4. When the click *G* is raised the ratchet wheel may revolve whilst the type and correcting wheels are stationary.

Change-over from Letters to Figures.

The object of the arrangement by which the type and correcting wheels may be relatively displaced by $\frac{1}{56}$ of a revolution is to provide for the printing of figures, signs, and punctuation marks as well as the letters of the alphabet. Consideration will at once show that the provision of a separate key for each character would considerably reduce the speed of working.

Instead of using two type wheels, one for letters and one for figures, punctuation and other signs, a single wheel is employed with the letters and figures placed alternately. When it is desired to print figures the type wheel is displaced to the extent of $\frac{1}{56}$ of a revolution. Each unit of time, equal to $\frac{1}{28}$ of a revolution of the chariot, which elapses allows the type wheel to turn through $\frac{1}{28}$ of a revolution, and thus the alternate characters are not printed. For instance, in printing "Jot" the "?" before "o" and the "×" before "t" are passed before the respective currents arrive. With the currents arriving with the same time intervals, but with the type wheel displaced $\frac{1}{56}$ revolution, the characters printed would be "0 (figure, not the letter)? ×." The 56 characters and spaces upon the type wheel are in order as follows:—

Blank Blank 1 *A* 2 *B* 3 *C* 4 *D* 5 *E* 6 *F* 7 *G* 8 *H* 9 *I* 0 *J* . *K* , *L* ; *M* : *N* ? *O* ! *P* ' *Q* + *R* − *S* × *T* / *U* = *V* Blank Blank (*W*) *X* & *Y* " *Z*

It will be shown later that the position of the type wheel is corrected every time the electromagnet is actuated. This is accomplished by the correcting cam which forces its way between two successive teeth upon the correcting wheel. Now, at two points upon the type wheel blank

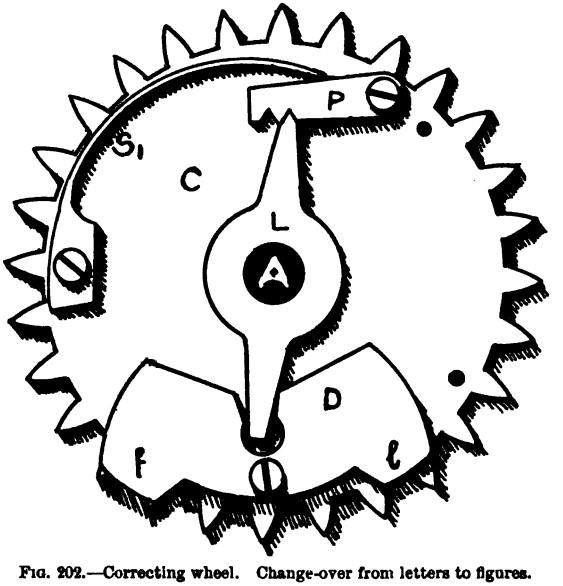


FIG. 202.—Correcting wheel. Change-over from letters to figures.

spaces are left, whilst either of the corresponding positions upon the correcting wheel may be occupied by the projecting portions of the "figure-changing lever." Referring to Fig. 201 it will be seen that the depression of the first or letter blank key will cause the cam to pass between the teeth opposite to *f*. As there is no character upon the type wheel at the point which is directly above the paper, a space is produced. If, however, the correcting wheel had moved so that the right-hand portion of the change-over lever was opposite the correcting cam, then this cam in

passing between the teeth would move the figure-changing lever upwards, thus causing the lever to engage the backward notch upon the pawl. This would be the case if the figure blank key was depressed. As already stated this displaces the type and correcting wheels by $\frac{1}{56}$ of a revolution, so changing over from letters to figures. The change back to letters would of course be made by depressing the letter blank key, when the correcting cam would reverse the position of the cross lever in the notches of the pawl.

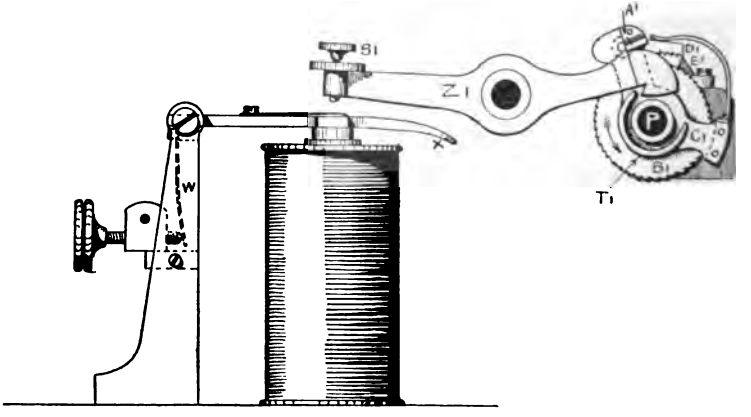


FIG. 203.—Electromagnet and printing axle ratchet.

FUNCTIONS PERFORMED AS THE RESULT OF RELEASING THE ARMATURE.

The passage of a current through the electromagnet releases the armature, and this upward movement is employed to bring about a mechanical connection between the printing driving axle and the printing axle proper. This connection causes the printing axle to make one complete revolution, and to disengage, *i. e.* every current produces a single revolution of the printing axle. By means of suitable cams and other devices in connection with this axle the following effects are produced :—

1. The position of the type wheel is corrected, and by the same action the change from letters to figures or *vice versa* is effected when required.

2. The slip is sharply brought into contact with the type wheel, so printing the letter.
3. The paper is moved forward.
4. The armature is replaced upon the electromagnet.
5. The electromagnet is disconnected until the armature has been replaced.

Printing Axle Entrained.

The impact of the armature upon the pivoted detent

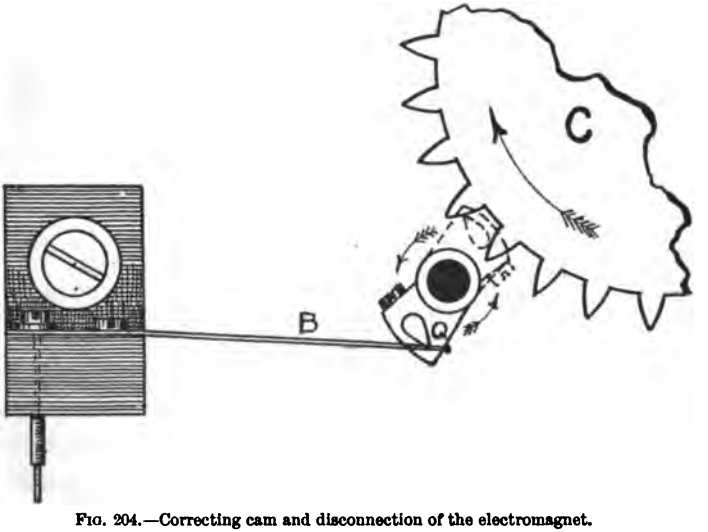


Fig. 204.—Correcting cam and disconnection of the electromagnet.

lever Z^1 (Fig. 203), depresses the further end of the lever, thus releasing the click D^1 which descends upon and engages with the continuously revolving ratchet wheel B^1. In this way the printing axle is entrained, but when the click has travelled about $\frac{7}{8}$ of the revolution it reaches the inclined plane E^1. The momentum it has acquired is sufficient to cause it to ride up the inclined plane, so disengaging from the ratchet wheel and finally bringing it back to its normal position of rest against the projecting portion of the detent lever.

Replacement of the Armature.

Upon the central portion of the click and click-spring arms an eccentric T_1 projects sufficiently far to engage the detent lever during revolution. It will therefore be seen that the eccentric raises the detent lever, and by means of the screw S^1 replaces the armature upon the cores. It will also be observed that the detent lever is in its normal position before the click disengages, and that it is therefore impossible for the click to over-shoot its normal position.

Disconnection of the Electromagnet.

The correcting cam Q (Fig. 204) normally rests upon and makes contact upon the spring B, but during revo-

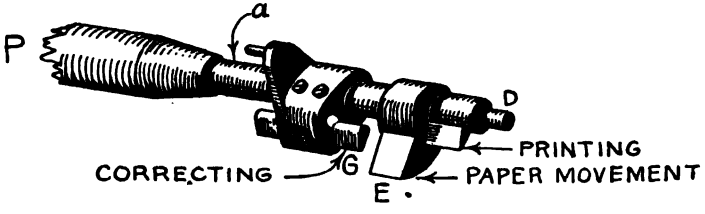


Fig. 205.—Printing axle cams.

lution this contact is broken. This serves to break the circuit of the electromagnet whilst the armature is being replaced.

Printing Axle Cams.

The other functions performed by the printing axle are effected by three cams attached to the printing axle. They are clearly shown in Fig. 205, and the function of each suitably indicated.

Correction for Synchronism.

The steel correcting cam Q, which is carried round by the printing axle engages with the correcting wheel, and is so adjusted that when the type wheel is in its correct position, *i. e.* when the letter to be printed is exactly

parallel with and wholly in contact with the tape, it lies between the teeth of the correcting wheel as shown by the dotted lines in Fig. 204. If the wheel is slightly behind the position it should occupy, the cam strikes the forward tooth, and so pulls the wheel round to its correct position, always provided that the actual and the correct positions do not differ by more than half a tooth. In a similar way the cam pulls the wheel back to the correct position if the wheel is in advance.

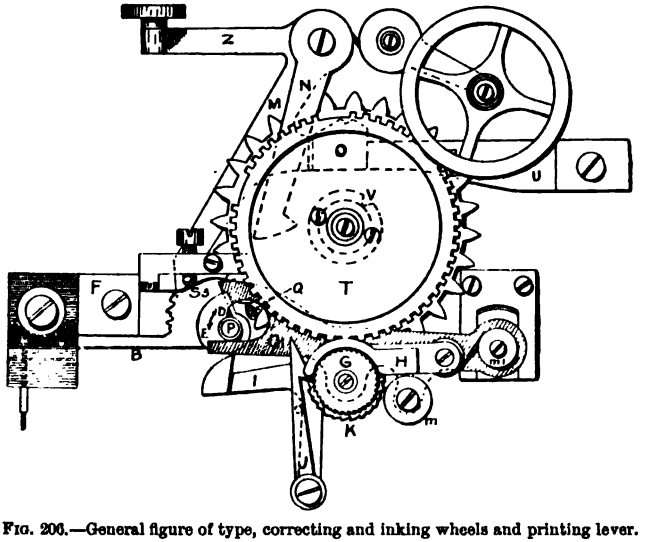


FIG. 206.—General figure of type, correcting and inking wheels and printing lever.

The correcting cam is of tempered steel, as also is the correcting wheel. The cam can readily be removed and another substituted whenever signs of wear appear.

PAPER MOVEMENT.

Referring to Fig. 206 it will be seen that the printing lever Q_1, pivoted at m_1 carries a second lever I, known as the paper-moving lever. The slip is carried under m over G, upon which it is pressed by the fork H. In the position shown the paper is in contact with the type wheel due to the cam D having completed rather more than half

a revolution. This cam, then, working in the forked end of the printing lever raises the paper against the type wheel whenever the printing axle makes a revolution. It should also be noticed that at the moment of printing the correcting cam is exactly midway between two successive teeth upon the correcting wheel. As it is equal in length to the distance between the teeth, the type wheel is steadied and this no doubt conduces towards the clearness of printing.

A revolution of the cam *E* causes the paper-moving lever *I* to descend to its lowest, and to then resume its normal, position. This downward movement causes the pawl *J* to turn the ratchet wheel to the required extent, and thus to move the paper forward. As the paper roller is contained upon the printing lever the motion of the paper moving lever does not withdraw the paper from the type wheel. The conformation and positions of the two cams are so designed as to reduce the speed of the type wheel as little as possible during printing.

Zero-Adjusting Lever.

It is of course essential that a means of stopping and starting the instruments at zero should be provided. This is effected by the zero-adjusting lever *Z* (more usually termed the "detent")—origin *Detente* French for Trigger —which is to be seen in Fig. 206. It carries two arms *M* and *N*, the former bearing a wedge-shaped projection.

The click *F* (Fig. 201) which engages with the ratchet wheel *R* carries a pin *q* which normally clears the inclined plane *o* (Fig. 206) carried upon the spring *U*. But when the zero-adjusting lever is depressed the wedge-shaped projection of the arm *M* moves the plane towards the correcting wheel, so that the pin comes into contact with, and rides up, the inclined plane, finally resting in the notch at its apex. This raises the click *F* (Fig. 201) from the ratchet wheel, so disconnecting the correcting and type wheels. The momentum which the combined type and correcting wheels have acquired is sufficient to carry them to such a position that the projection upon the arm *N* (Fig. 206) banks against the forward side of the notch *V*, and the pressure upon the adjusting lever is sufficient to complete the movement already described.

Now the wedge and the inclined plane lock together by means of a suitable catch, and the zero-adjusting key therefore remains depressed. At this point the letter blank portion of the type wheel stands directly above the paper.

If now the letter blank key is depressed a current will be sent out immediately the chariot passes over the letter blank pin. This current causes the printing axle to revolve, thus forcing the correcting cam between the teeth of the correcting wheel, thus moving it forward sufficiently far to permit the click *F* to fall upon and engage the ratchet wheel. As the locking between the arm *M* and the inclined plane *O* is of a very slight character the connection is broken, and the pressure of the spring *U* acting upon the wedge restores the zero-adjusting lever to its normal position.

It will be remembered that the printing at the sending station is effected mechanically by an extension of the chariot contact arm, and reflection will show that if both instruments are stopped by means of the zero-adjusting lever both will be started at the zero position when either station depresses the letter blank key.

Connections.

The full connections of a Hughes instrument are depicted in Fig. 207, and it will be noticed that two switches, respectively termed the "Hughes" and "motor" switches, are provided. The functions of each of the five positions of the Hughes switch are shown in the following table.

Hughes Switch.

Position of Switch.	Functions of Switch in each position.
1. "Receive −" 5. "Receive +"	Determines the direction in which the coils of the electromagnet are connected between line and earth.
2. "Regulate −" 4. "Regulate +"	Disconnects the coils of the electromagnet and earths the line through the 250Ω resistance coil.
5 "Duplex sending"	Disconnects the coils of the electromagnet and changes the connections so that the line is earthed after each current has been sent out.

When the direction of the current received is such as to increase, instead of to reduce, the magnetism of the electromagnet cores, the Hughes switch at the receiving

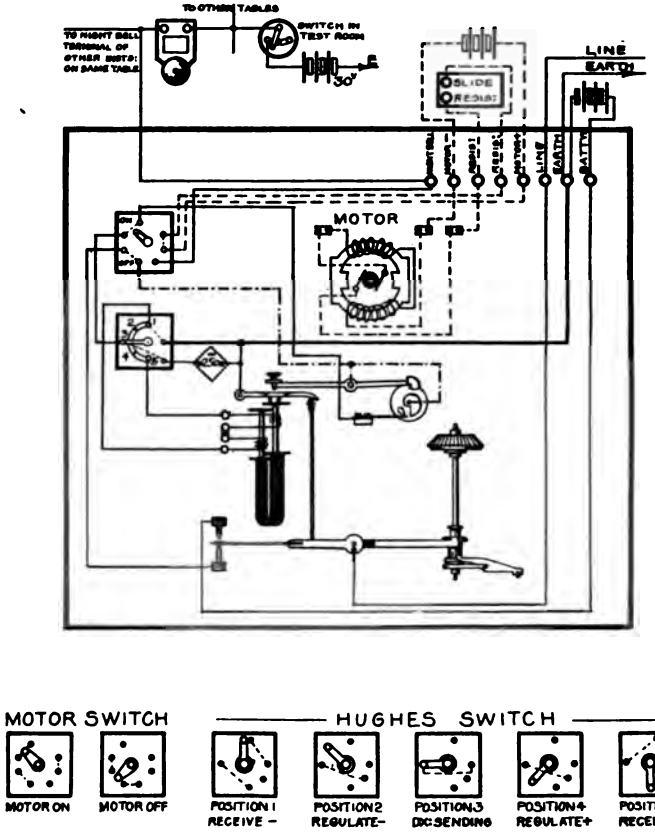


FIG. 207.—Connections of a Hughes set.

end is turned from position 1 to position 5 or *vice versa*. Reflection will show that the provision of this reversing arrangement is preferable to a battery reversing switch, since the receiving office would have to notify the sender that his battery must be reversed.

The two positions marked "regulate" produce identical connections. The coils are disconnected and the spring in connection with the correcting cam is connected to the armature. In this way a path to earth through the 250ω coil is provided. If the armature is upon the cores the path is through the correcting cam and spring, but if raised then the path is viâ the armature.

The "duplex sending" position is dealt with under duplex working.

The motor switch, in the "on" position, joins up the electro-motor. In the second position the connections are changed so that the rising of the armature connects the "night bell" terminal to earth. In this way calls are registered during the hours when the continuous attendance of an officer at the circuit is not necessary.

The remaining connections are quite obvious and call for no further comment.

Manipulation.

The actual manipulation of a Hughes instrument needs a very considerable amount of experience. Firstly, it is necessary to acquire the correct "touch," since by pressing the keys too heavily the pin is thrust out of its orifice, and the chariot passes over without sending out a current. Insufficient pressure usually results in some letters being missed and others duplicated. Secondly, it is essential that characters should be printed as frequently as possible, and the chariot should never be allowed to make a complete revolution without one or more signals being sent out. The operator feels the chariot pass over the raised pin because the rejector pushes the pin outwards, and thereby allows the key in connection with it to slightly descend. In this way the sender is apprized of transmission of each and every signal. The more frequently characters are printed the more often is the type wheel corrected for synchronism, and the more perfect is the accord between the instruments. So soon as the sender begins to miss revolutions there is risk of the instruments running out, and it may be said that until a learner is able to finger the keys accurately at such a speed as never to miss a revolution it is impossible for him to work a circuit.

Conventional Signals.

In the practical operation of the apparatus the following conventional signals are employed :—

Signal.	Indicates.	Reply Signal.
*Blank N Blank N Blank	Call	Blank N Blank N Blank.
*Blank Blank	All right. Yes. Understand.	
+	End of message.	
R (followed by figure)	Number of messages received in last batch.	
— — (word) — —	Word or words between underlined.	
*Blank E J O T Blank E J O T	Wish to test for loss of speed	Blank E J O T repeatedly.
*Blank I N S Blank I N S	Wish to regulate magnet	Blank I N S repeatedly.
N Blank N Blank	Correction, rub out.	
*Blank I T Blank I T	Wish to test synchronism	Blanks repeatedly.
I N	Used to interrupt or stop the sender	Both stations set their instruments to zero.

* These signals should be read by sound.

Preparations before Connecting the Instrument to Line.

Before placing the apparatus in connection with the line the instrument should first of all be oiled, care being taken to use the oil sparingly. The contacts should next be examined and cleaned if necessary—all paper, dust, etc., should be carefully removed. In fact absolute cleanliness is essential.

The electromagnet should now be adjusted as previously described upon page 374, and finally the apparatus should be tested for loss of speed. Firstly by printing Blank *I N S* in one revolution and then Blank *E J O T*, each set being continuously repeated several times. If these signals are printed satisfactorily the apparatus may be connected to the circuit, but, if not, it is necessary to trace and remedy the

defect. This may be due to a variety of causes, for instance, it would be produced by the rejector not clearing the pins, abnormal friction at several points, etc., etc. There should, however, be little or no difficulty in locating the seat of the trouble.

Here it may be well to point out that signals should never be sent until the apparatus has attained its full speed, since damage to the ratchet wheel and its click would inevitably result.

Adjustment for Equality of Speed.

The instruments having been connected to the circuit at each end it is first of all necessary to adjust their speeds so that they shall correspond as nearly as possible. This is accomplished by receiving a series of "blanks." If the home instrument is running faster than the distant one it will be obvious that letters will be printed in the order *A B C D E*, etc., instead of the blanks which should be recorded. But should the home instrument be running too slowly *Z Y X W V* will be printed. This adjustment is effected by means of the thumb-screw upon the governor which raises or lowers the "bobs," so respectively increasing or decreasing the speed as desired.

The next adjustment is made as follows:—The distant station sends out a blank at every revolution of the chariot. At the receiving end the current is cut off for an interval of about five revolutions, so assuring that the speeds of the two type wheels differ by less than half a tooth in the five revolutions. Finally the current is cut off for ten revolutions, and, if the blanks continue to be received correctly, the instruments are in sufficiently satisfactory accord for practical working.

The final adjustment of the electromagnet is made during the reception of the conventional signals "Blank *I N S*." This adjustment is usually of a very fine character and is made by means of the screw in connection with the antagonistic spring. The sliding keeper upon the electromagnet should not be employed as the alterations produced are far too large. It should be borne in mind that the adjustment of the electromagnet is of vital importance, and

that nine-tenths of the faults in actual practice are solely due to its defective adjustment.

Effects of Retardation.

Upon a long circuit there is, of course, a considerable amount of retardation. If the two type wheels both have their blank positions above the paper at the instant when a signal is sent out from the first station a letter will probably be printed at the distant station. This will be due to the fact that during the time taken by the current to appear at the distant end the type wheel is moving forward. The actual time may readily be measured by observing the letters printed when each station alternately depresses the "letter blank key."

In practice the sole qualification for satisfactory working is that the currents transmitted shall not merge into one another—the actual time occupied by the current in rising to the value necessary to work the instrument being immaterial. Supposing that the retardation amounted to a quarter of a revolution of the type wheel it will be obvious that the distant type wheel would not be released until a quarter of a revolution later than the sending station's, hence the characters would be received correctly. Upon the other hand both instruments must be stopped at zero before the direction of sending is changed.

The speed of working, which is directly proportional to the speed at which the chariot revolves, varies with different circuits. Upon a long circuit the speed has to be reduced in order (1) to prevent isolated currents being lost, and (2) to avoid the prolongation of a series of closely spaced currents (*e. g.* as sent when signalling "*I N T*"). In the second case the successive currents would merge into one another owing to the capacity of the circuit being so large that the earthing of the line is insufficient to clear it of charge. Hence the charge increases in value with each closely spaced current, the final result being that an extra letter or two is printed due to prolongation.*

* If the reader does not follow this statement it is advisable that p. 318 should be referred to, since the present case is but an obvious extension of that which has been said in regard to the speed of working upon Wheatstone circuits.

In the case of inland circuits the speed of working is limited by the skill of the operator, and is about 220 letters (120 revolutions of the chariot) per minute. Upon the London-Rome circuit the speed is about 160 letters, but in this case there are four repeaters in circuit (Paris, Lyons, Turin, and Florence).

Hughes Duplex.

The Hughes apparatus is very frequently duplexed, but invariably by the bridge method. As this method has received ample consideration in Chapter X. it will only be necessary to indicate the features which are special to Hughes working. In the first place, signalling condensers cannot be employed, since their effect in clipping the first portion of the received signal is of far too serious consequence (*vide* page 339). They cause the line to be charged to a much greater extent before the instrument is actuated, and so reduces the frequency with which the signals may follow each other without running together. This more than balances any gain from the point of view of the sending end.

Duplex Resistance Coils.

The duplex resistance coils are of similar design to those used in connection with Wheatstone circuits, but are wound to a resistance of 1000$^{\omega}$ (instead of 3000$^{\omega}$) per coil.

Electromagnetic duplex coils were experimentally tried, but without sufficient measure of success to justify their retention. These coils consist of a differentially wound electromagnet with closed magnetic circuit (Fig. 208). By this arrangement a current dividing between the line and compensation circuits merely experiences the resistance of the coils

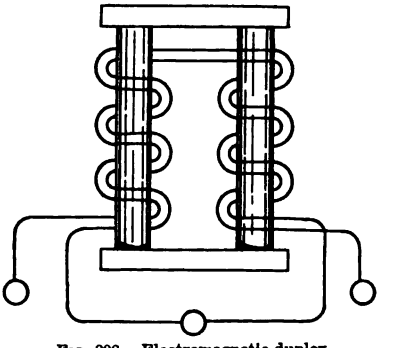


Fig. 208.—Electromagnetic duplex resistance coils.

since the windings oppose each other, and the iron, therefore, is not magnetized. A received current in passing through the coils in series magnetizes the iron, and therefore the large self-inductance comes into play, so that the resistance of this derived circuit is enhanced. This, of course, means that the first part of the received current flows almost entirely through the receiving apparatus.

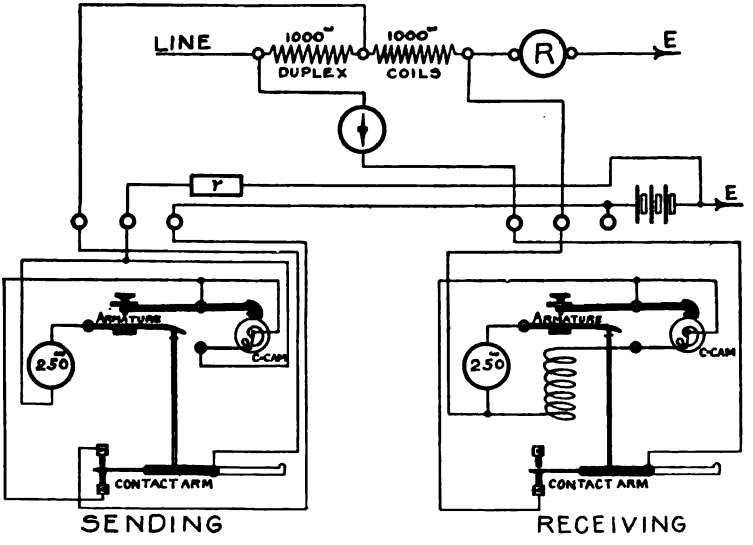


FIG. 209.—Principle of duplex working and skeleton connections.

ELECTROMAGNETIC LEAK.

Another device which has been employed to substitute signalling condensers is termed an electromagnetic leak. Upon either side of the duplex resistance coils an earthed electromagnet is connected. The self-induction produces an effect similar to that of a signalling condenser by offering a very high resistance to the first portion of the sent current, whilst its ohmic resistance only is active when the current has attained a steady state. In this way a heavy rush of current into the cable results, but as this proceeds a larger and larger proportion shunts through

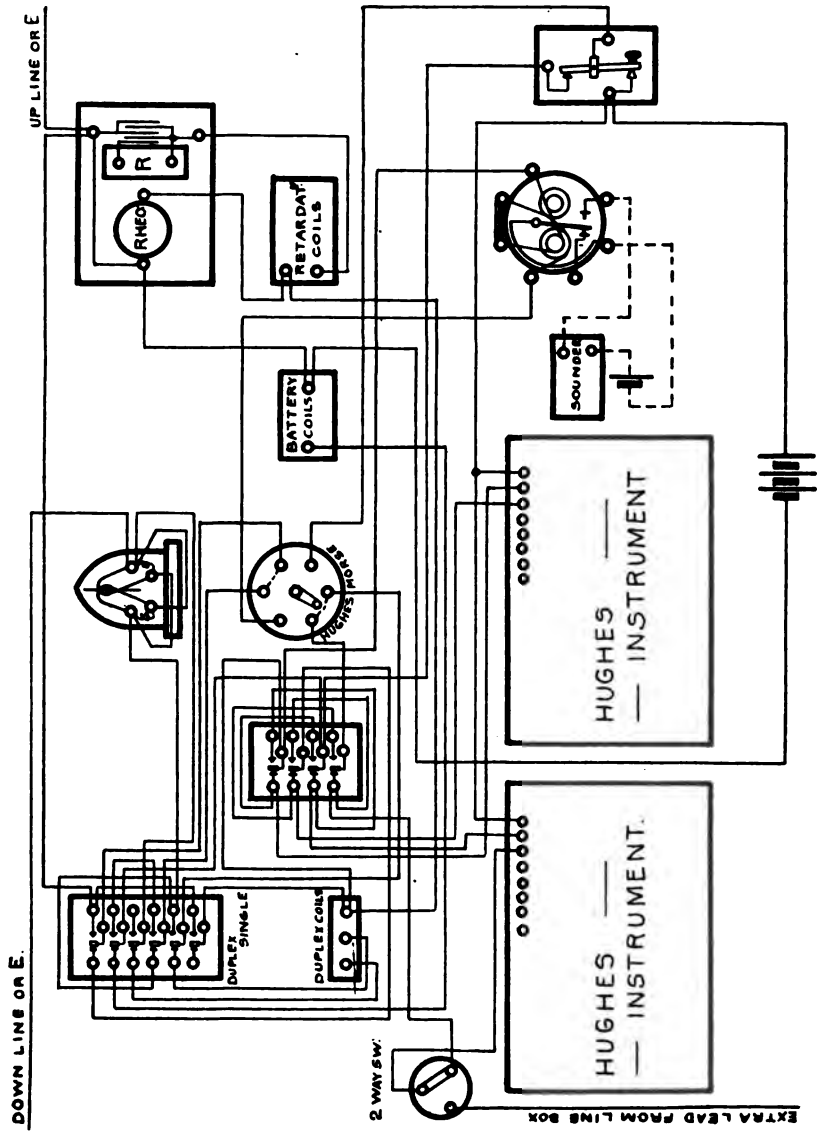


FIG. 210.—Full connections of duplex set.

the electromagnetic leak. Upon cessation or reversal of the current the E.M.F. of self-induction tends to help the withdrawal and reversal of the charge. It must, however, be confessed that the results obtained from this device, although beneficial, are not of very great importance. The device has, however, found a good deal of favour in France, Germany and Switzerland, and has been much developed by M. Godfroy, who designed three standard types :—

No. 1. 500$^{\omega}$ resistance and self-inductance, variable from 10 to 40 henries.

No. 2. 750$^{\omega}$ resistance and self-inductance, variable from 15 to 80 henries.

No. 3. 1000$^{\omega}$ resistance and self-inductance, variable from 20 to 120 henries.

The self-inductance is, of course, varied by adjusting the distance between the armature and the cores of the electromagnet by means of suitable thumb-screws. In France the use of these leaks at either end of long circuits is stated to have made it possible to reduce the number of repeaters in circuit. Once the correct value of the self-inductance required has been obtained the adjustment is not again interfered with.

The device is in use upon a few Wheatstone worked cable circuits at the repeater stations, but with a somewhat different object. It has never been used to any considerable extent by the Post Office.

Connections.

The connections for duplex working are shown in skeleton in Fig. 209. It will be noticed that a resistance equal to the internal resistance of the battery is employed to prevent disturbance of the distant balance in just the same way as that used in the single current sounder duplex (*vide* p. 237 and Fig. 102). The internal connections of the instrument are changed to those shown, by turning the Hughes switch to position 3 (*vide* Fig. 207). The signals sent out are, of course, registered mechanically at the sending instrument by the extension upon the contact arm. Immediately the contact lever falls back to its normal position the line is earthed through the 250$^{\omega}$ resistance and the battery coils, the former being short circuited instantly the correcting cam and its spring make contact.

The receiving instrument should call for no comment save that the 250ω coil is interpolated between line and earth when the armature rises, the electromagnet being thus shunted $\frac{1}{5}$.

The duplex and single switch is of the 6-bar type and is equivalent to six 2-way switches operated by a single lever. Its connections, although complex, should present no difficulty.

A 4-bar switch is provided so that the two instruments may be crossed as a whole, and thus either may be used for sending or receiving as may be desired.

Balancing is effected by means of the Morse, which is substituted for the Hughes apparatus by means of the 6-terminal 2-position switch. Upon international circuits a spring receiver is employed in place of the standard relay. The apparatus is also employed for communications with the repeater offices upon the circuit.

The connections of the apparatus for duplex working are shown in Fig. 210, but the connections of the first five terminals, which are necessarily the same as those of Fig. 207, have, for the sake of simplicity, been omitted.

CHAPTER XIII

TELEGRAPH SWITCHING SYSTEMS.

Introductory.

IN the early days of the telegraph the Umschalter switch was employed for connecting circuits together in order that messages might be signalled direct, thus avoiding the labour of re-transmission. This practice was subsequently abandoned, but within recent years the system has been re-introduced in a modified form. Generally speaking, telegraph switching may correctly be regarded as the application of the principle of the telephone exchange to telegraph circuits. Up to the present time it is not proposed to link together main circuits, nor yet local to main lines, for the direct transmission of messages. The objection to this course would lie in the serious reduction in the message-carrying capacity of the long and costly circuits. There are also many other difficulties to be overcome, such, for instance, as the comparatively unskilful operating of the sub-office assistant as compared with a highly-trained and expert telegraphist.

The Post Office employ two switching systems, firstly, the Concentrator, and secondly, the Intercommunication system in vogue in London. The former has for its object the saving of space and economy of operating charges at the Head Offices where it is employed. The Intercommunication system was devized in order to expedite the transmission of purely local London messages. Whilst the means of rapid transit from point to point of the City have been continuously increasing, the telegraph business of the Central Telegraph Office has rapidly expanded. This growth has greatly complicated the already difficult

problem of the rapid internal circulation of messages. It will be obvious that these unavoidable delays have unfortunately brought the time of transmission of a local message within measurable distance of the time occupied in other means of communication. This matter assumed so serious an aspect that a remedy had to be found without delay, and the method chosen was to arrange for an intercommunication switch at the Central Telegraph Office by means of which the local circuits could be linked together and thus signal their messages direct to the office of destination, so avoiding the delay inseparable from transcription, sorting to the particular circuit over which they were to be resignalled, and the re-transmission itself.

THE CONCENTRATOR.

Introductory.

In the larger offices there is a number of circuits upon which the traffic is under 150 messages per day. These circuits are connected to the concentrator, where they each terminate with an indicator and a switch-spring or "jack," as it is frequently termed. A number of sets of apparatus, which can generally be less than the number of circuits, is provided, each terminating in a peg with which connection can be made to any of the circuits upon the switch. Immediately any office calls, thus actuating the indicator, a set of apparatus is connected to the circuit by the switching clerk and the message is received. Messages to be sent to the various offices are similarly dealt with, save that the switch clerk makes the required connection at the request of the operator in charge of the set of apparatus from which the message is to be signalled. Means are provided for a signal to be given when the message has been disposed of, so that the switch clerk may disconnect the circuit and join up any other requiring attention.

Generally speaking it is inadvisable to connect more than two types of circuit to one concentrator, but there is, of course, no electrical reason why this should not be done. In the case of A.B.C. circuits the indicators are of the non-polarized shutter form, whilst for single needles, double

plate sounders, and sounders, they are non-polarized indicator relays. The working sets consist of three types, A.B.C., double plate sounder and sounder, the latter being so arranged as to work either single or double current as may be necessary.

Recently there has been a tendency to connect fairly busy circuits to the switches, allowing them to remain plugged through to apparatus sets during the busy hours of the day.

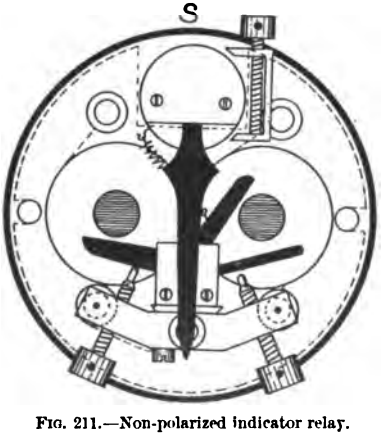


FIG. 211.—Non-polarized indicator relay.

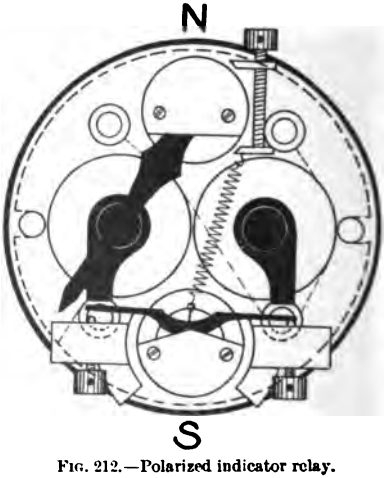


FIG. 212.—Polarized indicator relay.

INDICATOR RELAYS.

The non-polarized indicator relay (Fig. 211) consists firstly of an electromagnet with a soft iron armature passing under the left and over the right-hand projecting core, away from which it is held by means of a light spiral spring, the tension being adjusted by the vertical screw at the top of the instrument. Secondly, a polarized soft iron needle is hung between the cores of the electromagnet, and this indicates the direction of the current flowing through the relay. The connections of the coils are brought to two brass bushes insulated from the base of the relay, whilst the armature extension carrying the contact point is brought to the lower right-hand bush. The right-hand contact screw is furnished with a platinum tip, whilst the left is tipped

with ivory. The two lower bushes are therefore in connection with the local circuit. The connections are made by means of screws passing through the bushes, and therefore serve the double purpose of holding the indicator in position and making connections. The relay is furnished with a green celluloid front plate—shown by the dotted lines—and upon this is engraved the name of the circuit to which it is attached.

For purposes of comparison the polarized indicator relay is shown in Fig 212. The main point of difference lies in the fact that the armature is fixed upon, and is polarized by, the second bar magnet *S*. It will also be observed that the polarity of the induced needle and the direction of winding the coils are opposite to those of non-polarized instrument. A current passing from left to right deflects the needle to the left in both instruments. The non-polarized type may be regarded as a combination of a polarized indicator and a non-polarized relay.

The Drop Indicator.

The drop indicator is used for A.B.C. circuits because the needle of a non-polarized relay would vibrate so rapidly and with such a small amplitude that the signal would be very indistinct and would be easily overlooked. The remedy would be to turn the handle of the A.B.C. very slowly or to provide a totally different type of indicator. The drop indicator is the more satisfactory remedy, since the falling of the shutter cannot well be overlooked. It consists of an electromagnet and soft iron armature held away from its cores by a spring. The armature is furnished with a projection which normally holds up a slightly tilted shutter. Immediately the armature is attracted the shutter falls, so calling attention. The armature is also furnished with a contact point, so that the local circuit may be used to ring a bell when continuous attention is not justified by the amount of traffic.

Switch Springs, or Jacks.

The switch springs employed are of the five-point type and consist of four springs and a body or foundation which carries the tube forming the entrance for the peg. The

four springs fit into straight nicks made in two ebonite washers, held together to the body by a screw. The circular brass tube fits into the foundation strip of ebonite, to which it is secured by a screw. The general arrangement is indicated in Fig. 213, whilst Fig. 214 indicates the con-

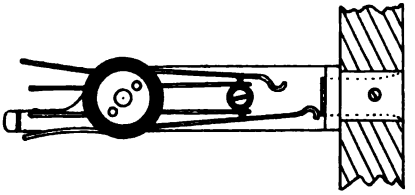


Fig. 213.—5-point switch spring.

ditions which obtain when a peg is inserted. The body is not used in the system under consideration, and merely serves the mechanical purpose of holding the peg in position.

Fig. 214.—Peg inserted in a switch spring.

Circular Peg.

The circular peg employed is divided into two sections, the ball or tip and the body. The metal parts of the peg

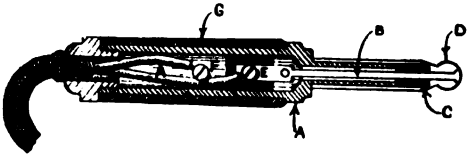


Fig. 215.—Two-section peg and cord.

are made in three parts. The part *A* (Fig. 215) is hollow, and an ebonite sleeve *C* is placed inside in order to insulate the rod *B*, upon the end of which is fixed the small ball *D*. Thus the screw marked *E* is in connection with the tip and *F* with the body of the peg *A*. The hollow

part *A* and the connections *E* and *F* are covered by the peg cover *G*, which is held in position by a small screw.

Cords.

The cords consist of two twisted strands of copper tinsel on a silk foundation insulated from each other with cotton, wrapped outside the strands. A braided covering is placed over both conductors. It may be remarked in passing that the exact arrangement of the cord differs with different

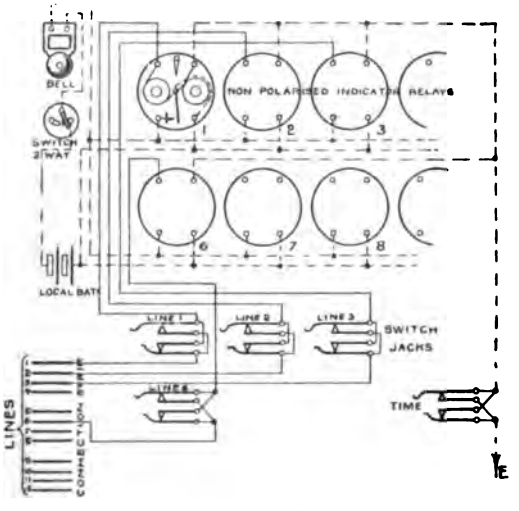


Fig. 216.—Connections of concentrator.

makers, but that a thoroughly satisfactory cord has yet to be designed. Formerly an iron wire was wound round the insulated conductors beneath the braiding, but even this was not effective. In later types of cord this has been abandoned, with the result that modern cords are slightly thinner than those of the older pattern. The point at which nearly all the faults occur is just outside the junction of the peg and the cord.

Connections and Working of Concentrator.

The connections of the concentrator are depicted in Fig.

216. The wires from the various stations connected to the switch are joined to the tags of the cross connection strip. This strip consists of an ebonite block to which are attached a number of tinned brass stampings. This enables the whole of the internal wiring to be carried out at the Factory.

If station I. works his key a current flows along the line through switch spring I, through the indicator relay, and to earth through the switch spring marked "Time." This causes the indicator relay needle to vibrate, and also closes the local circuit, so ringing the bell. During the day-time, or at all events during the busy hours of the day, continuous attention is given, and the bell is cut out of circuit by means of the two-way switch, the vibration of the needle being a sufficient signal. It will be noticed that the two

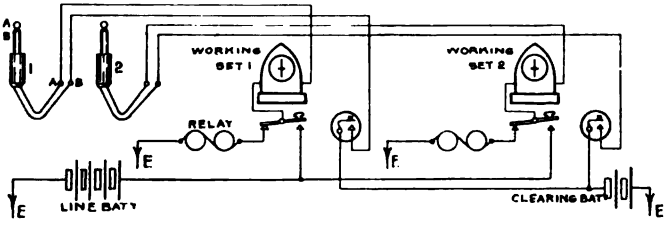


FIG. 217.—Apparatus connections for concentrator sets.

contacts between the inner and outer springs of the switch spring are placed in parallel, so that the failure of one of these contacts only would not disconnect the circuit.

Each working circuit is connected to a two-way peg, and, upon observing a call, the switch clerk takes any disengaged peg and inserts it in the switch spring in connection with the calling station. This is shown in the case of circuit III. The currents from station III. now pass through working set II. viâ the following path:—From tag 3 through the short spring and tip of the peg, through the working set to earth. The working set is joined up precisely as Fig. 217. The insertion of the peg causes the outer springs to break contact with the inner ones, thus disconnecting the indicator relay from the line. The sleeve, or body of the peg, however, now joins the indicator relay to the clearing battery and press button.

This is done in order that the telegraphist in charge of working set II. may actuate the indicator relay by depressing the button, so instructing the switch clerk to disconnect the circuit. It will be obvious that a vibrating needle

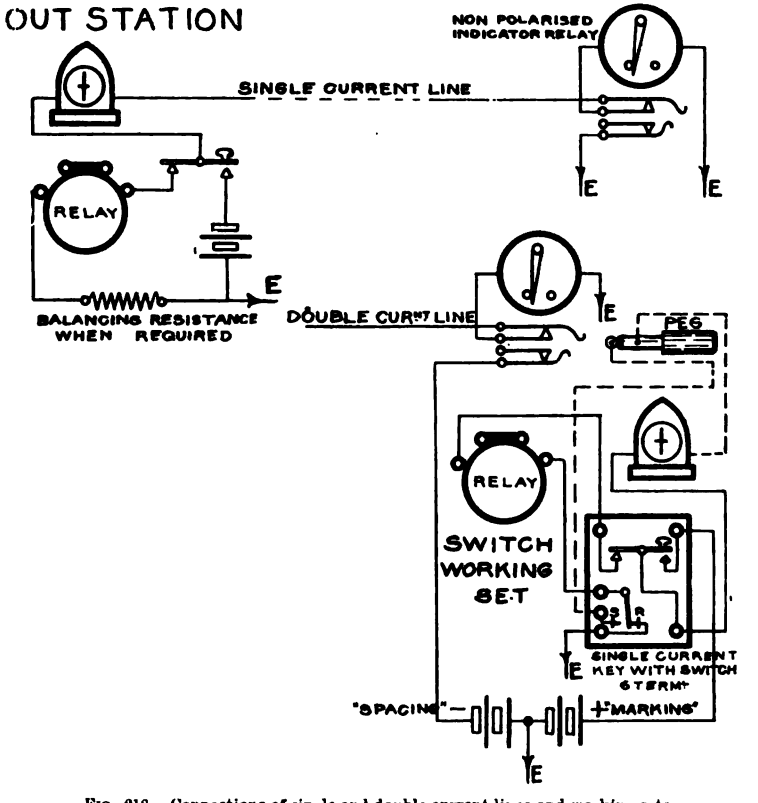


FIG. 218.—Connections of single and double current lines and working sets.

means a call when no plug is inserted in the switch spring attached to the line, and when a plug is inserted it means a disconnecting or clearing signal.

"Time" Arrangements.

The whole of the indicators are connected together and pass to earth through the "Time" switch springs. By inserting a peg in this switch spring the whole of the circuits upon the concentrator are bunched together, and thus "Time" may be signalled to all the stations simultaneously from one working set.

Battery Power and Balancing Resistances.

The resistances of the various local circuits which it is desired to connect to a concentrator usually differ very considerably. Since any working set may be connected to any circuit employing the same type of apparatus, it will be obvious that the battery power (usually provided by universal working) upon each set must be adequate to work the longest circuit. The circuits of lower resistance would consequently receive currents very considerably in excess of the proper values. Where intermediate offices were in circuit much difficulty would be experienced at the terminal station owing to the difference between the currents received from the head office and from the intermediate station. In a similar manner, difficulty at the intermediate station would also result. In order to avoid these difficulties, balancing resistances are employed. These resistances are, in each case, equal to the difference between the resistance of the circuit under consideration and that of the highest circuit connected to the switch. They are placed in the *receiving* circuits of the terminal stations in order to economize battery power; for, were they placed in the line circuits, it will be obvious that the batteries at the terminal stations would have to be correspondingly augmented. As the line current from the terminal station does not pass through the balancing resistance, the power employed is precisely the same as that required when working with a set specially allotted to the circuit at the Head Office.

For obvious reasons A.B.C. circuits require no balancing resistances. In the case of single needles the resistance is inserted between *X* and *Y*, whilst in relay worked apparatus (*e.g.* double plate sounder and single and double current sounder) it is placed in series with the relay.

Where a circuit to be connected to a concentrator has intermediate offices, the battery power at those offices must be increased sufficiently to provide for the effect of the

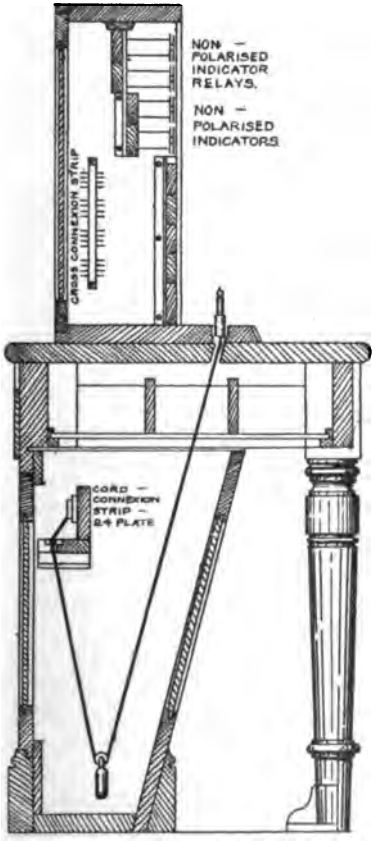


FIG. 219.—Sectional side view of concentrator fixed upon an instrument table.

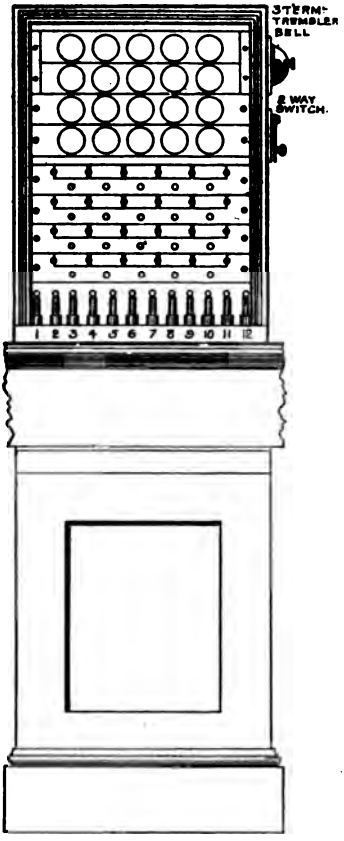


FIG. 220.—Front view of concentrator.

balancing resistance at the terminal station. In such cases the power employed at the intermediate station exceeds that used at the terminal station.

Single and Double Current Circuits Connected to the Switch.

Where it is required to connect both single and double current sounders to a concentrator the "electrical clearing signal" has to be sacrificed. A special 6-terminal single current key is employed upon the working sets, and the short spring of the switch spring is used to join up the spacing battery or not, according to whether the circuit is single or double current. In the former case it will be seen that the receiving relay is put to earth even when the switch is to "send." In the latter the spacing battery is joined up to the key. This should, however, be quite apparent from Fig. 217.

General Arrangement.

The general arrangement of the switch itself is clearly indicated by Figs. 219 and 220.

LONDON METROPOLITAN SWITCHING SYSTEM.

Number of Circuits Required.

The system has been designed to deal with the whole of the purely local traffic by direct transmission, but it will at once be obvious that traffic to and from offices not connected to the switches with switch offices has to be provided for. In other words, besides intercommunication similar arrangements to those described in the case of the concentrator are also required. For this latter purpose 200 working sets will ultimately be required. The number of circuits connected to the switch is as follows—

300 switch wires to offices which only collect telegrams.
650 switch wires to offices which both collect and deliver telegrams.
200 working sets for sending and receiving messages which cannot be dealt with by through switching.

This gives a total of 1150 circuits to be connected to the switch, but of these 300 are for traffic inwards to the switch and are not required to be used, save in exceptional

circumstances, for outward traffic. It is therefore necessary to arrange for 850 circuits to be capable of being connected to each other in both directions, whilst the remaining 300 need only be capable of being connected to any of the 850 circuits, but not to each other.

Many of the larger offices have sufficient traffic to and from non-switch stations to fully occupy one or more direct wires to the Central Telegraph Office. Accordingly a suitable number of such circuits, usually duplexed, is provided in each case.

Each office is designated by a number, and suitable street lists, showing the offices to which messages for every address within the metropolitan area should be sent, are provided at each office.

Multiple Switch.

Thirty-six switch clerks are employed to perform the work of connecting the various circuits together in accordance with the calls received. Each clerk is given a certain number of these circuits, and is responsible for answering and attending to every call *from* them. The group of circuits allotted to any operator is known as the "Home" section of that particular board.

It will be seen that, since any one of these circuits may require to be connected to any other of the 850 circuits, each of them must be within reach of every switch clerk. This condition is readily satisfied by the adoption of the principle of the multiple switch-board which is used in all the larger telephone exchanges. Allowing 2′ 6″ as the sitting accommodation for each switch clerk, and 7′ 6″ as the total space occupied by a complete switch-board at which three operators are seated, it will be seen that the central operator would readily be able to reach to the furthest extent of the switch-board both to the right and to the left. If, therefore, the whole of the 850 circuits are placed upon one of these complete switch-boards, every circuit will be within the reach of the centre switch clerk, whilst the outside switch clerks will respectively be able to reach the first and last thirds of the adjacent boards, which are of precisely similar construction. At the beginning of the boards the last third would have to be repeated for the use of the

first switch clerk, whilst at the end the first third would have to be placed immediately upon the right of the last complete board. In this way every one of the 850 offices would be within the reach of each switch clerk.

Need for the Engaged Test.

Since, however, there are ten complete boards the 850 circuits will have to appear upon each of the boards, and an indication as to whether the circuits are engaged or free will be essential. For instance, circuit 562 might be connected by switch clerk No. 1 to one of the "Home" circuits upon that board, and at the same time might be required by switch clerk No. 20 for connection to one of the "Home" circuits which terminate upon that board. In order to avoid this difficulty a small lamp indicator is placed above each switch spring, and these lamps are simultaneously lit upon all the multiple sections immediately the circuit to which they refer is connected by any of the switch clerks.

Method of Operating.

Before entering upon the description of the electrical arrangements required for the working of the intercommunication system it is essential that the method of operating should be clearly apprehended. Each office connected to the switch is represented by a miniature electric lamp, for indicating, and by a switch spring for answering a call. At the out-station an "indicator key" is provided, which is depressed when attention is required. This key causes the calling lamp at the switch to light, and so advises the switch clerk that attention is required. In addition to this every office is connected, as already mentioned, to a number of switch springs, so arranged that every office is within the reach of each operator for the purpose of making a connection from the offices for whose calls that switch clerk is responsible to any circuit connected to the switch. The connections are made by means of pairs of pegs and cords in connection with each of which is a speaking key and a clearing lamp, the former for bringing into circuit the switch operator's sounder and Morse key required for receiving and answering calls, and the latter for indicating the conclusion of the transaction.

The switch clerk upon observing a call takes a peg and inserts it in the adjacent switch spring which is connected with the calling station. This operation puts out the calling lamp, and releases a visual shutter on the indicator key at the out-station, thus indicating that the call is being attended to. The switch clerk moves over the speaking key, corresponding to the peg used, thus bringing into circuit her Morse sounder and key. Immediately the out-station observes that the indicator key is released, the number of the office with which connection is required is signalled continuously in abbreviated figures. The switch clerk listens to at least two repetitions of the number, in order to avoid error, then makes the required connection with the second peg of the pair, and restores the speaking key to normal. The two offices are then in communication and the message is signalled direct.

Upon completion of the message the indicator keys at both out-stations are pressed, and this lights a lamp attached to the pair of cords with which the connection has been made. This serves as an instruction to the switch clerk to sever the connection, which is done as speedily as possible. The indicator keys are thereby released at both offices, showing that a new call may now be made by either. In fact the conditions are then exactly as they were before the connection was made, *i. e.* the calling lamps and relays are again joined up.

In order to save work and time on the part of the switch operator all connections required for the working sets at the Central Telegraph Office itself are made by means of the Morse key instead of by the indicator key. The call "*T S*" causes the calling lamp to flicker instead of giving a continuous glow. The switch clerk upon seeing a flickering glow merely connects the circuit to a working set without speaking. Such connections are, of course, required whenever the message is for an office not connected to the switch-board.

It may be noted that since a connection *to* any office may be made by any switch clerk it is necessary to provide a means by which it can be indicated whether the circuit is engaged or free. This is accomplished by a small lamp indicator placed above each switch spring. This lamp is lit whenever a peg is inserted in any

switch spring connected to this particular office, and the switch clerk can therefore see at a glance whether any particular circuit with which connection is required is engaged or free. In the former case the "MQ" signal is given to the calling office, and a second request is made later on; after a message has been offered three times without result, special steps are taken by the switch clerk to obtain the connection as quickly as possible.

Before passing on to the principal electrical arrangements, it is proposed to describe some of the more important pieces of apparatus used in conjunction with this system.

Polarized Sounder.

The polarized sounder (Figs. 221, 222 and 223) is an instrument which may be used in place of a single needle dial, a relay and sounders (in the case of the double plate sounder), a directly worked sounder, or a sounder with relay (either single or double current), and either simplex or duplex. It can only be used where a loud sound is not required, and it would therefore be of little service in a large instrument room where many ordinary sounders were in use in adjacent positions. At sub-offices, however, its use could certainly be greatly extended. Its use in place of a single needle dial or a double plate sounder is sufficiently obvious. By giving it a bias to one side, so that it permanently rests upon one sounding piece, it may be used in place of a sounder. It would under such conditions require a comparatively small current, and could therefore be economically worked direct over the longest of minor circuits. Without bias and without the springs holding the needle in the centre it can readily be used for double current working. Since it is differentially wound it could be used for duplex working. It is, however, in connection with the intercommunication system that the instrument has been most extensively employed. Its external appearance has been slightly modified, and it is singly wound to a resistance of 5400$^{\omega}$, with a 27,000$^{\omega}$ shunt (joint resistance 4500$^{\omega}$) instead of differentially to a resistance of 200$^{\omega}$ (100$^{\omega}$ per coil). It is used as a directly worked double current instrument.

The electrical and magnetic parts of the apparatus are

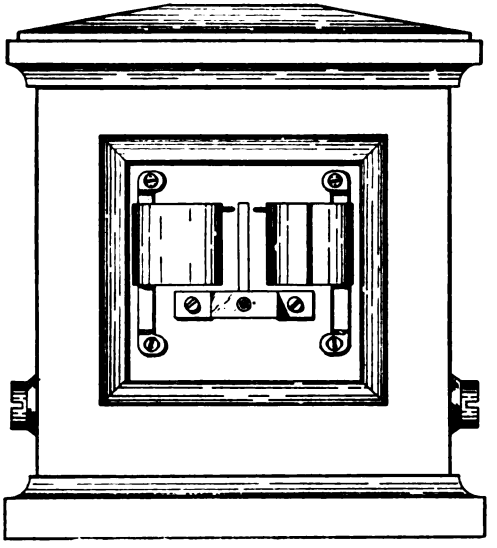


FIG. 221.—Front view of polarized sounder.

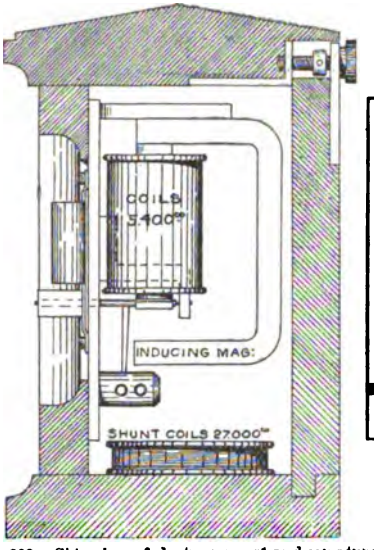


FIG. 222.—Side view of electro-magnet and armature.

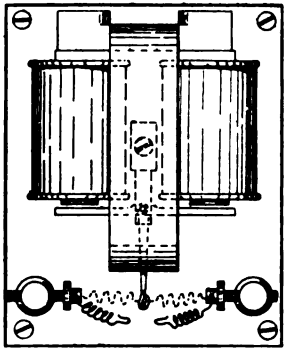


FIG. 223.—Back view.

clearly shown in Fig. 223. They consist of an electromagnet with a polarized soft iron armature connected to the striker in front of the dial. The inducing magnet makes the ends of the cores into South poles, whilst the ends of the armature are made North by induction (Fig. 222). The passage of a current through the electromagnet causes the armature to be strongly attracted by one core and repelled by the other. The springs hold the armature and hence the striker in a central position. Without them, the armature would remain upon either side in just the same way that the tongue of a relay when set neutral will remain in contact with the stop against which it is placed.

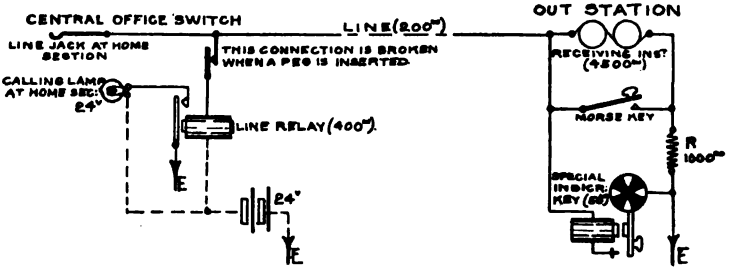


FIG. 224.—Skeleton connections of a circuit under normal conditions. (NOTE.—The power connected to the line relay has recently been raised from 24v to 36v.)

THE INDICATOR KEY.

Another piece of apparatus which calls for a brief description is the "indicator key 50ω" which is depicted diagrammatically in Figs. 224 and 225. When this key is depressed a contact is made between the lever and the stop, and the current flowing through the coils of the instrument then keeps the armature attracted, and the circuit is maintained until the current is removed. The armature then flies back and the indicator key circuit is broken. Attached to the lever of the key is a disc divided into 12 parts alternately white and black. Above this is placed a black plate with spaces cut out so as normally to show the black parts of the key disc. When the key is depressed the disc is rotated, and the white parts are seen through the holes in the upper disc.

The construction of the instrument resembles the non-

polarized relay used in conjunction with P. O. telephones, with the addition of the plunger and a wide space between the normal and marking contacts of the tongue. The plunger carries a suitable spring to return it to the normal position immediately the current is interrupted.

Other Apparatus.

The pegs, cords, and switch springs are somewhat similar to those described in the case of the concentrator, but the pegs and switch springs are of a simpler and smaller type.

The translating relays are upon page 190.

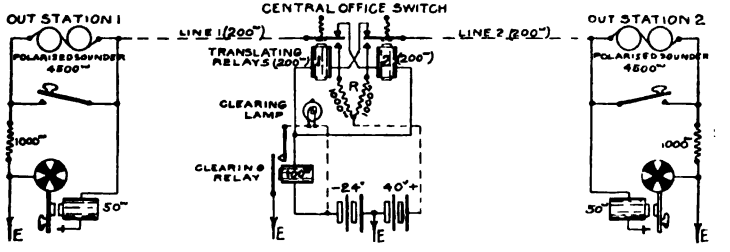


FIG 225.—Skeleton connections of circuit when two offices are connected together at the switch. (NOTE.—The power used on the negative side of the battery has recently been raised from 24v to 36v.)

Connections of a Disengaged Circuit.

The skeleton connections of a circuit under normal conditions are depicted in Fig. 224. Normally a permanent current of 6 m.a. flows over the circuit from the 36 volt battery. This current has no effect upon the comparatively unsensitive line relay, but it is sufficient to produce a deflection upon the polarized sounder. If the indicator key is now depressed the resistance of the circuit is reduced by very nearly 5500Ω, which increases the value of the current to 55 m.a., so actuating the line relay and also holding over the armature of the indicator key. The permanent closing of the local circuit of the line relay lights the calling lamp, thus signifying that a connection with an office upon the switch is required. If instead of closing the indicator key the Morse key had been worked the current would only have been increased to 24 m.a., but this

current is quite sufficient to work the line relay, and therefore the call "*T S*" would have produced a flickering glow upon the calling lamp, so indicating that the message was for an office not connected to the switch, and would therefore have to be received on one of the working sets.

Two Circuits Connected Together.

Immediately the switch clerk pegs into one of the switch springs on the calling line, the calling apparatus in connection with this line is cut out of circuit, the engaged indicator is actuated upon each of the multiple switch-sections, and, by a momentary disconnection of the battery, the out station's indicator key is released. The speaking key is turned to the "speaking" position and the call is thus received upon the switch clerk's sounder. If the called office is disengaged (shown by the lamp indicator), the second peg of the pair is thrust into the switch spring of that office upon the multiple. The speaking key is then returned to the normal position, and the conditions depicted in Fig. 225 result. A spacing current flows over both lines from the 36 volt battery viâ the following paths:—from the positive pole of the 36 volt battery to earth, through 1000$^{\omega}$ resistance coil at station I., through the polarized sounder, along the line, through the contacts of relay I., through relay II., through the clearing relay to the negative pole of the battery. The path to station II. is similar, save that the current passes through the contacts of relay II. and through relay I. There is therefore a spacing current of about 6 m.a. upon each line which serves to hold the polarized sounders against the pins of the left-hand sounding pieces, but which is not sufficient to actuate either the translating or clearing relays. If now station I. works his key the resistance of the circuit is reduced by 4500$^{\omega}$ when the key is depressed, since the polarized sounder is then short circuited. This increases the current through relay II. to 24 m.a., which causes the armature to descend. This connects the positive pole of the 40 volt battery through 1000$^{\omega}$ and the lever of relay II. to line 2, so reversing the direction of the current received at station II. It will, therefore, be seen that when the key at station I. is worked translating relay 2 is actuated in accordance with the signals sent from

the key, and that this sends out double current signals to station II. The working may therefore be described as single current *to* the switch from the sending station and double current *from* the switch to the receiving station. When station II. depresses his key relay I. is actuated and double currents are sent to station I. Since a current of about 50 m.a. is needed to work the clearing relay, it will be seen that it also is unaffected by any of these currents.

Clearing Signal.

When the message has been completed both offices depress their indicator keys, so actuating the clearing relay and lighting the lamp. The action is slightly different at the switch and depends upon which of the two stations first depresses his indicator key. If station II. is first, then the clearing relay is actuated through the coils of relay I., contacts of relay II. and through the depressed indicator key to earth and back to the battery. The value of the current is 66 m.a., and the circuit of the indicator key is continuously maintained. The descent of the armature of relay I. puts a marking current due to 40 volts on the line I., and, when the indicator key is depressed, the current rises from 6 to 32 m.a., which holds over the indicator key. Similarly if station I. first depresses his indicator key, No. 2 translating relay is actuated; this will, however, be obvious. Immediately the clearing signal is observed the pegs are withdrawn, the indicator keys are thereby released, and the conditions of Fig. 224 restored.

Speaking Apparatus.

The switch clerk's speaking apparatus consists of a key and a relay and sounder. The key earths both the translating relays when depressed, thus causing both armatures to descend, and so sending out a marking current to both stations, or to only one of them if only one peg is inserted. The speaking relay is joined up in place of the clearing relay, by means of the speaking key on each pair of pegs and cords, and is thus actuated in accordance with and when either of the translating relays are worked by the stations.

Collecting Offices.

It has previously been pointed out that there are a number of offices which only collect and do not deliver messages. In such cases connections *to* these offices are but seldom required, and therefore it is unnecessary to connect them to the multiple sections of the switchboard. Each of these circuits terminates in a peg furnished with a speaking key and a lamp which does duty both as a calling and as a clearing signal. The depression of the indicator key lights the lamp and the switch clerk then enters the circuit by means of the speaking key. After ascertaining the number of the office with which connection is required, the peg is lifted from its place and the calling lamp is at once darkened. This is accomplished by a socket contact which is broken when the peg is in its normal position, and which is made when the peg is raised. The peg is then inserted in the switch spring of the called line, the speaking key is returned to normal and conditions somewhat similar to those of Fig. 225 obtain. The difference lies in the fact that the lamp and its relay serve the double purpose of calling and clearing. When the indicator keys are depressed this lamp is lighted and the connection is severed. The advantage of this arrangement is that the operation of inserting the first peg of a pair in the home switch spring is saved. It may therefore be said that one-half of the operation is already done when single cord working is adopted.

Engaged Test.

The principle of the engaged test is shown in Fig. 226. When a peg is inserted in any switch spring the body of the peg connects the body of the switch spring to its long spring. In this way the double-tongued "cut off" relay is actuated, so cutting out the calling apparatus and, at the same time, actuating all the "engaged" indicators. In the event of the failure of this "engaged" device the condition of any circuit can be ascertained by touching the bush of the switch spring with a peg connected to an earthed lamp. If engaged, the 36 volt battery being connected to the bush of the switch spring, therefore causes the earthed lamp to glow when connected by tapping with this special peg provided for the purpose.

Intermediate Offices.

There are certain cases in which two offices share a single switch wire. The intermediate and down stations are connected to the line in leak, and the resistance of each is raised so that the total permanent current sent out to both offices is the same as that sent out upon a one

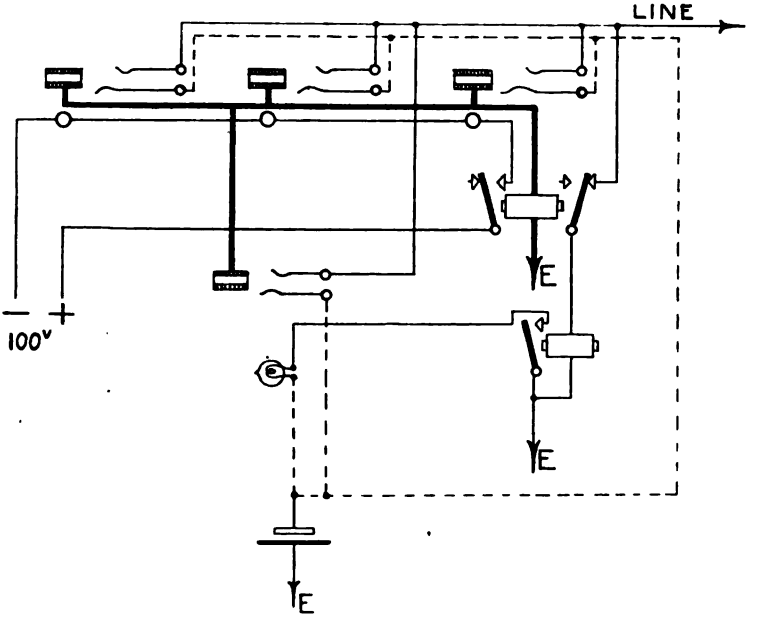


Fig. 226.—Engaged test and connections of switch-springs upon the multiples and home sections.

office circuit. In both cases this reduces the received working currents to half the value of that obtained upon a circuit without an intermediate station upon it. It is, however, found that satisfactory working may be obtained with this reduced current, and it only remains to indicate the arrangements by which either station may ascertain whether the other office is working. At the intermediate office a differential galvanometer, with its coils in parallel, is placed in the line circuit, while a 900$^{\omega}$ single current galvanometer

is joined in series with the polarized sounder at the down or terminal station. The current which passes through the translating relay when the key is depressed is precisely the same as in one office circuits, and therefore no special adjustment of the translating relays is required. When the down office is working the current of 24 m.a. which passes along the line deflects the differential galvanometer at the intermediate station, so indicating that the circuit is engaged. The key at the intermediate station disconnects the down station every time it is depressed, and so causes the needle of the 900$^{\omega}$ galvanometer to oscillate.

The down station's indicator key when depressed produces a large deflection on the differential galvanometer. The intermediate indicator key cuts off practically all current from the down office, which clearly indicates the condition of the circuit to that office.

Provincial Switching System.

It is important to notice that in the case of the metropolitan switching system all the circuits are underground and that care has been taken to bring them up to a standard resistance of 200$^{\omega}$, exclusive of apparatus. In this way the currents through the relays are always the same, no matter what office is working upon them. The result is that the regulation of the translating relays is quite stable and adjustments are only required at infrequent intervals.

The system will no doubt be introduced into the populous areas surrounding the larger provincial cities, but as the circuits will not be wholly underground it will hardly be possible to employ the system described. The most obvious method of dealing with the problem is to provide for single current sounder working and to use batteries at each office. The clearing signal could be given by means of a reversing button or key which would actuate a polarized signal at the head office. Translating relays would not be needed nor would a multiple switch be required, at any rate, for the present, as the number of circuits would not in any case be more than one-tenth of the number to be dealt with in London.

Other Details.

The intercommunication system also meets the following requirements;—

1. Two speaking keys cannot be simultaneously depressed by a switch clerk.

2. Greenwich "Time" is signalled by a bunching arrangement resembling that of the Concentrator, but only one line is taken in the case of offices having two or more lines.

3. Two offices may be placed upon a single switch circuit when necessary by connecting them in parallel and arranging so that the resistance *from* the switch is the same as for one office.

4. A pilot lamp to show that all calls are promptly attended to and to prevent the failure of a calling lamp from causing a stoppage of the circuit without such failure being known. This also provides for the ringing of a bell at night when any station calls.

5. Special arrangements are made for the rapid removal of defectively adjusted translating relays and for their readjustment by means of a testing set.

6. A special device to automatically indicate when any particular pair of circuits is free. This is to ensure that, where an office has been waiting for another for some time, the waiting office shall have the next turn.

The details of these arrangements would occupy far more space than is available in the present volume, and the reader who requires fuller details is referred to *Telegraph Switching Systems*, by T. F. Purves, to which work the author is indebted for the whole of the information contained in this chapter.

THE CENTRAL BATTERY DUPLEX.

It has been pointed out that many offices require direct circuits to the Central Telegraph Office in addition to the "switch" wires. These circuits are frequently required to work duplex, and a very simple and ingenious system has been invented by T. F. Purves as an adjunct to the Metropolitan Switching System. Its main features are the reduction of the apparatus required to a minimum, the retention of the polarized sounder, and the absence of all batteries at the out station. It is also remarkable from the fact that an office having, say, two switch wires and two duplex

direct circuits may have all the sets joined up so that in the event of the failure of one of them either of the other sets may be employed as a substitute.

After the description of the quadruplex system the Purves duplex should present no difficulty, since the fundamental principles employed have already been fully considered. The system adopted is however that of *decrement* in preference to the *increment* system generally used for quadruplex working.

The connections of the apparatus at each end are shown

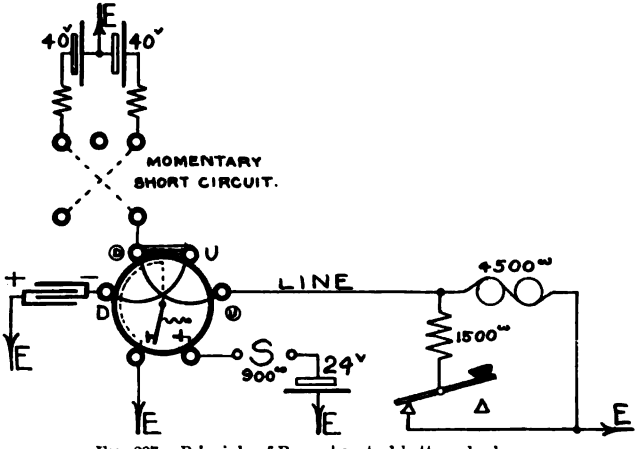


FIG. 227.—Principle of Purves' central battery duplex.

in Fig. 227. At the out station the line passes through the 4500ω polarized sounder with a single current key and a 1500ω resistance coil normally joined across its terminals. The joint resistance at the out station is therefore 1125ω. The depression of this key increases the resistance of the apparatus from 1125ω to the full resistance of the polarized sounder (4500ω), and it is this increase which brings about the actuation of the relay at the central office by reducing the current and allowing the tongue to fall back against the marking stop. The polarized sounder is worked by the currents sent out from the double current key through one coil of the non-polarized relay.

The tongue of the relay is normally held away from the marking stop by the current passing to line, and when this current is reduced by the depression of the key at the out-station the biassing spring on the relay pulls over the tongue and registers a signal. Since the marks are thus registered by the relay spring and not by the current, it is obvious that when reversals of current take place through the relay coils, as the home key is worked, there is no tendency for the marks to split at the moment of "no current," as would have been the case had the marks been registered by the current against the force of the antagonistic spring as in the case of the increment system. False marks due to splits in the spacing currents can be avoided by a fairly wide adjustment of the relay contacts. The disadvantage of having to insert an uprighting sounder in order to preserve the character of the signals is thus avoided. On very short circuits no compensation is required and the relay coils are joined in series, but on the longer metropolitan circuits, which have a capacity from ·5 to 1·5 microfarads, one of the relay coils is joined to earth through a small condenser. But for this provision the momentary rush of current required to reverse the charge in the line, should it take place at the time a mark is being registered, would be sufficient to overcome the tension of the antagonistic spring of the relay, and splitting of the marks would result.

It will thus be seen that the out station's sounder is actuated by the currents sent out from the double current key, whilst the central apparatus is worked by the decreased current resulting from the depression of the out station's key.

The 1500$^{\omega}$ shunt at the out station reduces the current through the polarized sounder but slightly, since the difference between one quarter of the normal current (key at rest) and the reduced current working the relay (key depressed) is small, and no difference in the strength of the signals received can be detected by the ear.

These circuits are closed at night by cutting off the battery, and each office can then obtain communication only through its switch circuits.

CHAPTER XIV

SECONDARY CELLS.

A SECONDARY cell or accumulator is a reversible primary cell in which chemical energy may be restored to the cell in return for electrical energy. It has previously been shown that when a current is taken from a primary cell the constituents of the cell are re-arranged in such a manner that the electrical energy produced is accounted for by the difference between the chemical energy possessed by the cell in its original and in its re-arranged forms. If an electric current is passed through an exhausted cell in opposition to its E.M.F., the chemical compounds re-assume their original form and a current may again be taken from the cell. In this operation electrical energy is transformed into chemical energy.

Every primary cell will, to some extent, behave as a secondary cell. Indeed, one of the first accumulators (Thomson-Houston) devised was a special form of Daniell cell. Upon the whole, dry cells are probably more efficient when used as secondary cells than any other type, but even in this case the arrangement is distinctly unsatisfactory since the re-charged cell does not even approximate in efficiency to a new cell.

The secondary cell of practice may be defined as a voltaic cell such that, when discharged, the elements form insoluble compounds with the electrolyte, which compounds may be converted to their original condition by the passage of a current in the reverse direction.

The secondary cell of to-day is the result of evolution from the celebrated "gas battery" invented by Grove in 1842. The latter consisted of two vertical glass tubes, each closed at one end, filled with, and dipping into, water to which a

little sulphuric acid was added to improve the conductivity. A platinum wire was fused through the closed end of each of the glass tubes, and to this wire was soldered a long thin strip of platinum foil which extended to the base of the tubes. Upon passing a current through such an arrangement by connecting a battery to the two platinum wires the water is split up into its constituent elements, viz. hydrogen and oxygen. The hydrogen follows the direction of the current and appears at the terminal connected to the negative pole of the battery, the oxygen appearing at the other pole. The gases are thus collected separately in the two tubes. It will be found that if the battery is removed and the two terminals of the gas battery are joined by a wire an electric current will flow from the pole which was joined to the positive pole of the battery to that which was joined to the negative pole of the battery. This current will continue until the whole of the oxygen and hydrogen have re-combined to form water. It will be obvious that this process may be repeated indefinitely, hence the gas battery may be described as a secondary cell having plates of hydrogen and oxygen. The difference of potential between oxygen and hydrogen or the E.M.F. of the cell is 1·47 volts, and therefore it is obvious that to charge the cell by decomposing the water an E.M.F. higher than this is necessary. Again, it is equally obvious that a number of these cells may be placed in series and charged by a source of E.M.F. greater than 1·47 volts multiplied by the number of cells in series.

The next epoch in the evolution of the modern secondary cell was made by Gaston Planté, who in 1860 invented the first lead cell. This cell consists of two lead plates coiled spirally, and separated from each other by flannel, the whole arrangement being immersed in dilute sulphuric acid. When the plates are connected to a battery having a sufficiently high E.M.F. to produce a current through the cell, peroxide of lead (PbO_2) is formed on the positive plate whilst the negative remains lead. Upon discharge, both plates are coated with lead sulphate ($PbSO_4$), which upon re-charge is converted to spongy lead at the negative and peroxide at the positive. The E.M.F. of the cell is about 2 volts.

The pole and plate which is connected to the positive

pole of the battery, and which, when discharging, is the positive pole of the cell, is termed the positive plate and pole. This convention differs from that used in the case of primary cells where the positive pole is the negative element. This is equally true of secondary cells, but convention and usage have established the nomenclature already mentioned, and it will now be understood that by the positive and negative plates are meant those to which the positive and negative poles of the battery or other sources of E.M.F. are respectively connected for charging purposes. The positive plate is readily recognizable by the brownish tinge which the peroxide of lead gives it during charge, whereas the negative partakes a greyish tinge.

When the elements have become fully charged, *i. e.* the complete peroxidization of the positive and reduction of the negative, the only effect of further charging is to decompose the water of the electrolyte into its constituents, hydrogen and oxygen, the former gas being evolved at the negative, and the latter at the positive, electrode. During discharge the active material in both plates is partially converted into lead sulphate, but these reactions will later be described.

Planté also discovered that by charging and discharging and then charging in the reverse direction the capacity of the cells could be greatly increased. This process was repeated many times before the cell had gained anything like its maximum capacity, and is known as the process of formation. Formation renders the surface of the plate more irregular and more porous, thereby increasing its active surface. The cell under this treatment continually gains in capacity until finally the plates fall to pieces from lack of mechanical strength. Unfortunately, the more efficient the plates become from an electrical point of view the worse they grow mechanically.

From the chemical standpoint, all secondary cells with lead plates and dilute sulphuric acid are exactly alike, although the details of design and manufacture may differ considerably. There are cells in which lead is only used for one element and some in which lead is not used at all, but the use of these cells is not at present sufficiently extensive to warrant description in any but treatises on secondary cells alone.

Every improvement upon the Planté cell has for its object the reduction of the costly and tedious process of formation, the improvement of the mechanical structure, *i.e.* the prevention of the destruction of the cell by the ever-increasing porosity of the lead, increase of the active surface, and reduction of the weight of the cell.

In 1880 Faure constructed and obtained the patent rights for a cell in which the active material was applied to the plates in the form of a paste instead of being produced by formation. Priority of invention is usually awarded to Metzger in 1878, but there is no doubt that Faure's results were independently obtained. Faure pasted both his plates with a paste formed by mixing red lead (Pb_3O_4) and sulphuric acid. The mixture formed lead sulphate ($PbSO_4$), and this upon the positive plate, was converted into peroxide of lead by the liberated oxygen, whereas upon the negative plate it was reduced to spongy lead by the liberated hydrogen combining with the acid radicle (SO_4). This paste of Faure's does not adhere very well to the plates, and hence many of the later improvements are directed towards the remedying of this defect.

The Planté and the Faure cells represent two great prototypes. In regard to the merits of the two types, it may be said that, comparing cells of the same dimensions, the pasted cell has a larger capacity, whilst the Planté type will permit a very much heavier rate of discharge without injury to the plates, but the improvements in both types of cell tend towards the elimination of this distinction.

Chemistry of Secondary Cells.

The chemistry of secondary cells is not known with any degree of certainty at the present time, and this notwithstanding the fact that many eminent chemists have devoted much study to it. The substances used as active materials are, in the first place, mixtures, and will not dissolve in any solvent without decomposition taking place, thus rendering a quantitative determination of the active constituents very difficult, if not impossible. Many theories, more or less complex, have been evolved, but none of them entirely explain the changes noticed.

The chemical action of all secondary cells of the lead-

sulphuric acid type is the same, for their only differences are in the form of the plates or grids and the method of preparing the active material. In cells of the Faure type the negative plate is pasted with a mixture of litharge (lead monoxide) and sulphuric acid, since this requires less energy to reduce than a higher oxide such as minium (Pb_3O_4), which is generally used for the positive active material. The effect of charging such a cell is to reduce the litharge or sulphate of lead, as the case may be, to spongy lead at the negative and to form lead dioxide at the positive. A charged Planté cell has the lead at the positive oxidized and spongy lead formed at the negative. The formation of the cell consists in producing the maximum quantity of active material (spongy lead and lead dioxide) upon the plates. It will thus be seen that charged cells, whether of the Planté or Faure type, are precisely alike as regards their chemical condition.

The theory which is now most favoured and which most nearly fits the experimental facts is known as the double sulphation theory. It owes its origin to Gladstone and Tribe, two of the earliest workers in the field, and very probably with slight modifications will prove to be true. Before the publication of their researches the electrolyte was held to be water, and the presence of the acid was regarded as merely improving the conductivity of the water. This theory is now universally admitted to be erroneous. The electrolyte is sulphuric acid, and according to the double sulphation theory the action may be represented as under :—

Charged.					*Discharged.*								
Positive.		Negative.			Positive.							Negative.	
PbO_2	+ 2 H_2SO_4	+	Pb	=	PbO	+	H_2SO_4	+	H_2O	+	$PbSO_4$.		
One molecule of lead dioxide	and	Two molecules of sulphuric acid	and	One atom of lead	form	One molecule of lead monoxide	and	One molecule of sulphuric acid	and	One molecule of water	and	One molecule of lead sulphate	

The monoxide of lead and sulphuric acid are shown bracketed together, since they react and thus form lead sulphate and water. This action is purely chemical as distinguished from electro-chemical, and therefore has no effect upon the E.M.F. of the cell.

Action at the positive pole :—

$$\underset{\text{One molecule of lead monoxide}}{PbO} + \underset{\text{One molecule of sulphuric acid}}{H_2SO_4} = \underset{\text{One molecule of lead sulphate}}{PbSO_4} + \underset{\text{One molecule of water}}{H_2O}$$

(and) (form) (and)

The final result of complete discharge is, then, to convert the whole of the active material upon both plates into lead sulphate and also to remove sulphuric acid from the electrolyte. Lead sulphate is, however, a very bad conductor, and therefore the *whole* of the peroxide is not acted upon, thus leaving at the end of the discharge a quantity of peroxide covered over by a coating of sulphate.

Charging changes the lead sulphate to lead dioxide upon the positive and to spongy lead upon the negative, which causes the positive plate to assume a deep chocolate and the negative a light grey colour. When the cells are dis-

FIG. 228.—Hydrometer.

charged the colour of the positive will be found to have grown lighter, though still of the same colour. The semi-transparency of the lead sulphate accounts for its not showing itself in the form of a grey colour upon the plates.

THE HYDROMETER.

From consideration of the equations given upon page 432, it will be observed that the percentage of acid in the electrolyte is greatest when the cell is fully charged and is least when it is completely discharged. The specific gravity of the solution is therefore an index to the charge or quantity of energy in the cell. It also serves as a guide to the behaviour and conditions of the cells. The type of hydrometer most frequently employed for testing the gravity is shown in Fig. 228. Its range is from 1·150 to 1·250, the gravity of pure acid being 1·840. The hydrometer is allowed to float in the solution, the gravity of which is equal to the value marks upon the scale at the level of the liquid.

Evidences for and against the Double-Sulphation Theory.

Having broadly considered the chemical action postulated in the double sulphation theory, it may be well to examine some of the experimental evidence in its favour. The conclusions of Robertson were as follows :—

1. The particles of peroxide soon get coated in the discharge with a layer of lead sulphate, which protects the peroxide from further action.

2. The analysis also shows that a proportion of active material remains at the end of the discharge.

3. The loose, powdery surface of the peroxide plate seems to be thoroughly converted into lead sulphate.

4. When the peroxide on the surface of the plate falls to about 31% the cell very rapidly loses its E.M.F., owing to the inactive layer of sulphate, which impedes the action of the sulphuric acid on the active material beneath, and also to the formation of peroxide on the negatives. The diffusivity of the action is decreasing, and it has to penetrate further and further into the plate to find the active material. When the whole of the paste approaches the composition of 31%, the cell loses its E.M.F. entirely.

5. The action seems to take place most rapidly where the current density is the greatest; the plate becoming hard there from sulphate soonest during discharge, and oxidizing there the quickest during charge.

In the case of the negative plates nothing but sulphate of lead and lead was found during charging.

These conclusions all confirm the double sulphation theory, and moreover they indicate how vitally important is the porosity of the active material, since this property means the free access of the electrolyte to material below the surface.

The objections urged against the theory are that there is some experimental evidence to show that spongy lead is an allotropic modification of ordinary lead, and that the lead dioxide formed in the cell is not normal dioxide. Fitzgerald suggested that it is hydrated peroxide. The very definite discharge equation must have an equally definite E.M.F., whereas the E.M.F. of a discharging cell is a constantly varying one. Even granting that the small but rapid drop

of E.M.F. generally observed during the first few minutes of a discharge and that which ends the discharge is the result of special reactions not included in the equation, it is nevertheless true that between these periods the voltage continuously falls. Against this objection we may set the fact that the electrolyte has been assumed to be sulphuric acid merely, whereas water is also present, and in ever varying quantities.

There is also evidence of the formation of persulphuric acid (H_2 $(SO_4)_2$), and it is to this reaction that the high E.M.F. observed at the end of the charge is ascribed. Persulphuric acid is a compound which absorbs energy in formation and liberates it in decomposition. It is very unstable, and almost immediately combines with water to form ordinary sulphuric acid and hydrogen peroxide (H_2O_2), which latter again splits up to form water and oxygen. Reasoning from these facts one is compelled to admit the formation of lead persulphate (Pb $(SO_4)_2$); and this would account for the difference between the E.M.F. during charge and discharge.

The polymerization theory due to E. J. Wade postulates a far more complicated structure for the spongy lead, dioxide, and sulphate. Briefly, this theory states that one is never dealing with dioxide alone or with sulphate alone, but with a far more complex substance which contains both.

To sum up the question so far as it has been investigated, it may be said that the double sulphation theory represents broadly the nature of the changes, although it is quite evident that there are other subsidiary reactions occurring at the same time.

Expansion of the Active Material on the Positives.

Before passing on to descriptions of the various types of secondary cell, it should be stated that in every form described the number of negative plates exceeds the positives by one. This is in order that both sides of the positive may be acted upon, and the tendency of each side to bend or "buckle," due to the expansion of the active material, may be made equal. For the same reason the positives are usually thicker and stronger than the negatives, which have but little or no tendency towards buckling.

The D.P. Cell.

In the "D.P." cell, which is one of the practical forms of Planté cell, the plates are built up of lead ribbon placed horizontally in a frame of lead alloy. These plates are formed by a special electrolytic process for which it is claimed that the active material is thereby produced out of the plate itself, so making the "protecting" coat extremely dense, whilst the oxides are in the best possible condition for electrolytic action.

Chloride Cells.

A third or intermediate class between Planté and Faure cells is sometimes constituted of those cells in which the plates are plugged with rolls of lead ribbon. As the active material is formed from these rolls, the cells may with propriety be considered as belonging to the Planté group. To this class belongs the well-known Chloride cell which is employed in connection with the Central Battery telephone system.

The cell derives its name from the method of preparing the active material for the negative plate. The process is as follows:—Acetate of lead, formed by dissolving litharge in a solution of acetic acid, is converted into chloride of lead by placing it in a solution of hydrochloric acid. Chloride of lead is insoluble, and therefore sinks to the bottom of the solution, from which it is readily removed. It is then pressed into slabs and dried in an oven, after which finely-powdered zinc is added and the whole melted up in crucibles. The mixture is then poured into a series of small hexagonal moulds, each of which has two small pegs, thus casting two holes in the pastille. A lead grid is then cast around each set of pastilles under great pressure, thus forcing the lead into very intimate contact with them. These plates are then formed in a solution of zinc chloride against zinc plates by connecting the zinc and lead plates respectively to the positive and negative poles of a dynamo, The zinc which would be deposited upon the negative plate combines with chlorine of the lead chloride and forms zinc chloride and pure lead, the former dissolving in the solution. The zinc which was mixed with lead chloride pastilles is also converted into zinc chloride, and

dissolves in the solution, thus leaving the lead in the pastilles in a very porous condition. The plates are then carefully washed and placed in a solution of sulphuric acid, where a current is again sent through them. Hydrogen is liberated at the lead plate, and this combines with

FIG. 229.—Chloride "R" type cell.

and removes any remaining traces of chlorine left by the previous processes. This is then the finished negative plate, which has, owing to the porosity of the lead in the pastilles, a very extensive active surface.

The lead-antimony mixture of which the positive plate

or grid is formed is run into moulds under an air pressure of 150 lbs. to the square inch, in order to ensure a perfectly homogeneous casting. The 124 circular holes are cast countersunk upon both sides of the plate so as to provide for the expansion (during formation) of the active material which they support. This active material consists of a tape of pure lead, which is gimped whilst cold with deep grooves and ridges under a pressure of 4000 lbs. per square inch. Suitable lengths are then cut off and wound into rosettes. The rosettes are inserted in the holes in the plate, which is finally subjected to heavy pressure, thus driving the buttons home and ensuring perfect contact. The plate is then subjected to a modified Planté formation process, during which the rosette is partially perozidized.

A complete cell of the "R" type is illustrated in Fig. 229. It will be observed that the plates are provided with shoulders resting upon the edges of two vertical glass plates within the cell. In order to preserve the separation between the plates, two long glass rods, the heads of which are to be seen in the figure, are inserted between each pair of plates.

The density of the electrolyte when placed in the cells is 1·215, which is also its value when the cell is fully charged. The cells should never be discharged to such an extent that the gravity falls below 1·175, although this figure is dependent to some extent upon the size and type of cell.

The capacity of the type of cell illustrated is 60 ampere hours per positive at the 9-hour rate. The cell illustrated has 15 plates, of which 7 are positives, giving a capacity of 420 ampere hours. The cell may be discharged in one hour, but in this case the capacity is only 210 ampere hours. There are, however, many cases in which it is essential that a heavy current may be obtained without risk of injury to the cells.

Modifications of the Chloride Cell.

As a result of experimental work on vehicle cells, a negative of the pasted type, known as the "Exide," has been constructed which overcomes many of the faults found in the other types of pasted plates. After a thorough test

under actual working conditions in both vehicle and stationary cells, the "Exide" negative has been adopted in place of the Chloride negative described above.

The grid is of the "cage" type, consisting of thin vertical ribs, the edges of which are flush with the faces of the plate, and which are connected by small bars having a

Fig. 230.—Chloride "R" type cell with Exide negatives and board separators.

triangular cross-section, the apex of the triangle being at the face of the plate. These connecting bars on one face are staggered with those on the other. The grid is filled with a special paste and subjected to a reducing process, the finished plate being $\frac{7}{32}$ inch thick. The active material is in the form of continuous pencils, of rectangular cross-section, extending from the top to the bottom of

the plate. The thin flat ribs are on two sides of the pencils, and the triangular cross-bars are embedded in the other two sides, which constitute the faces of the plate. The continuity of the material combined with the cross-bars holds it firmly in place, while at the same time provision is made for its expansion and contraction.

The new form of cell (Fig. 230) then comprises positive plates of the new "R" type (Fig. 231), which are slightly

FIG. 231.—Chloride positive plate.

thicker than the old "R" plates, and the rosette has been modified so as to render buckling impossible and increase the life of the element. Another important change consists in suspending the plates from the edges of the glass cells instead of from glass plates inside.

The glass rod separators of the old type have been abandoned in favour of board separators supported from the bottom of the cell by wooden dowels at each corner, which being without perforations form practically a con-

tinuous diaphragm between the plates, thus preventing short circuits. By using these board separators, cleaning is found to be necessary at less frequent intervals and the life and capacity of the elements are therefore considerably prolonged and the efficiency increased. It is found that this method of separation does not increase the internal resistance of the cell.

It may be remarked that for vehicle purpose the positive and negative grids are of identical construction, both being of the Exide type, differing only in their active material.

E.P.S. Cells.

The cells made by the Electrical Power Storage Company are of the Faure or pasted type, and are the results of the labours of Faure, Sellon, Volckmar, King and others. Until recently the E.P.S. cell was the only type employed by the Post Office for telegraph purposes. At the present time a very large number of these cells are in daily use, and most are of the "K" 7-plate type.

The "K" positive plate consists of a thick lead grid with horizontal grooves, running right across the plate, cast in a slightly downward direction, and slightly burred over (see Fig. 232, showing a portion of the plate).

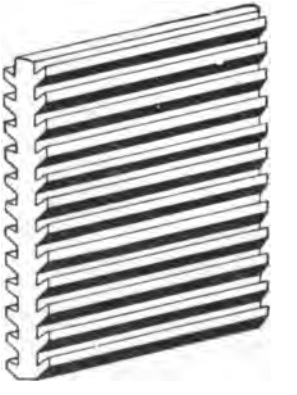


Fig. 232.—Portion of E.P.S. "K" type positive grid.

This plate is pasted with a mixture of red-lead and sulphuric acid, thus forming lead sulphate.

The "K" type negative, which is about one-half the thickness of the positive, consists of a grid in which a leaden projection arises from each of the four sides of each square hole (Fig. 233). These claw-like projections serve to hold the active material firmly in position. The paste for the negative consists of a mixture of litharge and sulphuric acid, as it is easier to reduce to lead than the positive paste would be.

The general appearance of the K 13-plate cell is illustrated in Fig. 234. It should be observed that the positive plates are connected to the main lug of the cell at the top of the plates whilst the negatives are connected together at the bottom to the leaden strip forming the negative lug. The object of the arrangement is to secure greater uniformity of action over the surfaces of the plates.

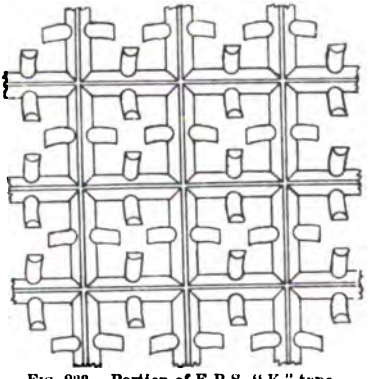


FIG. 233.—Portion of E.P.S. "K" type negative grid.

The plates are separated by means of two

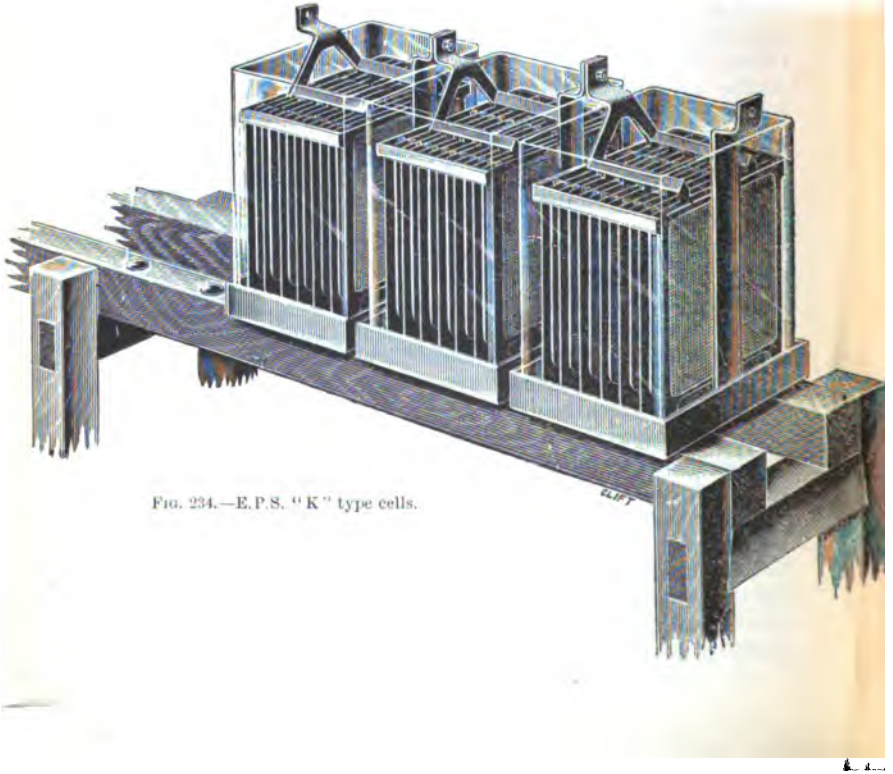


FIG. 234.—E.P.S. "K" type cells.

ebonite forks placed over each positive. The section as a whole rests upon an H-shaped piece of paraffined wood, thus raising the plates above the bottom of the cell, and so preventing any danger of short circuits produced by falling paste.

The "K" cell has now become obsolete and its place has been taken by the "W.S." type. The plates in the W.S. type are somewhat heavier and larger and the arrangement of the grids is totally different. The positive plate is $10\frac{1}{8}$ inch square and ·35 inch in thickness, and is triangularly grooved upon both sides. These grooves do not extend continuously from side to side of the plate, since the plate is strengthened by twelve ribs of metal which extend from the top to the bottom of the plate. These details will, however, be rendered quite apparent from consideration of Figs. 235, 236, 237 and 238.

The negative grid (Figs. 239, 240 and 241) is divided into twelve sections or panels by three vertical and two horizontal ribs. Between these ribs a fine lattice is extended, which provides 114 oblong holes for the reception of the paste. These holes taper from the centre to the outside of the plate, as indicated in Fig. 240 and 241.

The general appearance of a 23-plate cell is shown in Fig. 242, and it will be noticed glass tube separators are employed in place of ebonite forks, and as these are fixed both at the top and the bottom the chance of buckling has been very greatly reduced. The new type of cell has a much higher discharge rate than the one it replaced. The 7-plate cell may be discharged in two hours, and for a discharge extending over seven hours has a capacity of 168 ampere hours or 56 ampere hours per positive.

The acid when placed in the cells has a density of 1·200. When the cell is fully charged the specific gravity should be 1·205. The discharge should cease when the gravity has fallen to 1·180.

Hart Cells.

The Hart cells, which are of the Faure or pasted type, are now used by the Post Office for all capacities up to 90 ampere hours.

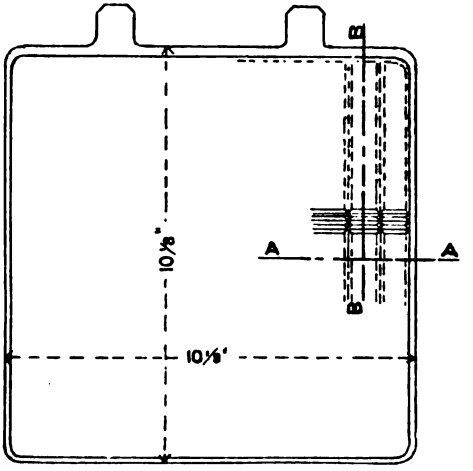


FIG. 235.—E.P.S. "W.S" type positive plate. ½ full size.

FIG. 237.—½ full size ection on line A A in Fig. 235.

FIG. 236.—½ full size section on line B B in Fig. 235.

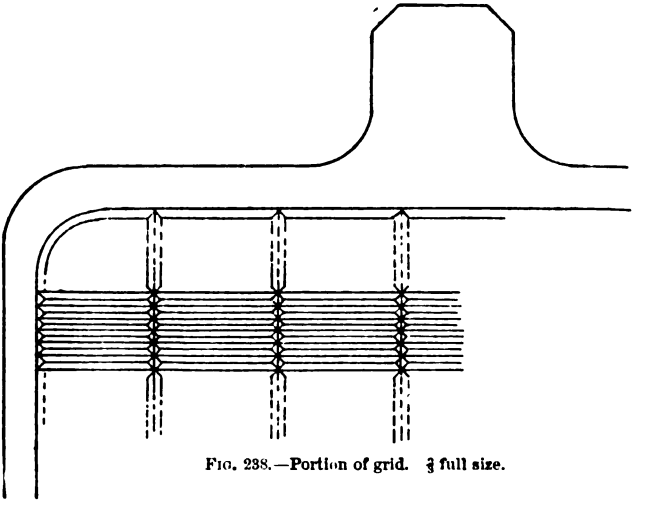


FIG. 238.—Portion of grid. ½ full size.

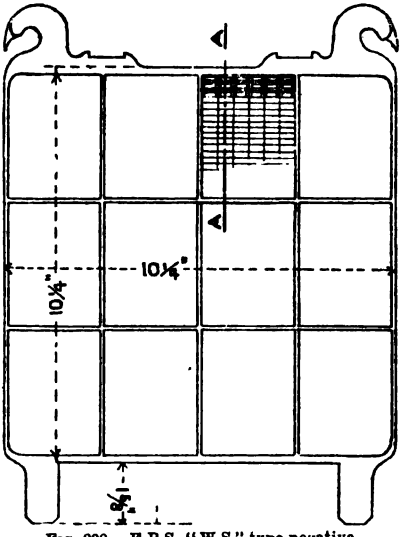


FIG. 239.—E.P.S. "W.S" type negative. ½ full size.

FIG. 240.—½ full size section on line A A (Fig. 239).

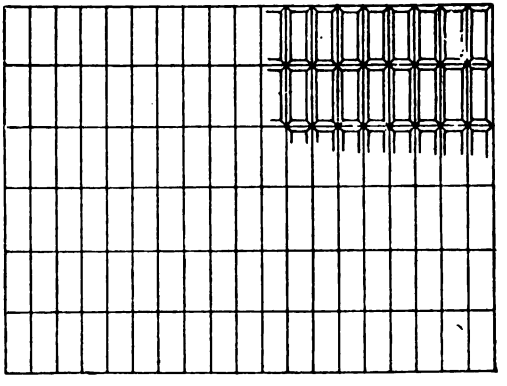


FIG. 241.—Portion of negative grid. ½ full size.

The positive grid (Figs. 243, 244, 245 and 246) is $\frac{1}{4}$ inch thick and upon either side it is divided into five vertical divisions, whilst two ribs extend approximately from corner to corner. Similar ribs extend from side to side of the plate, and of these there are twelve to the inch. The

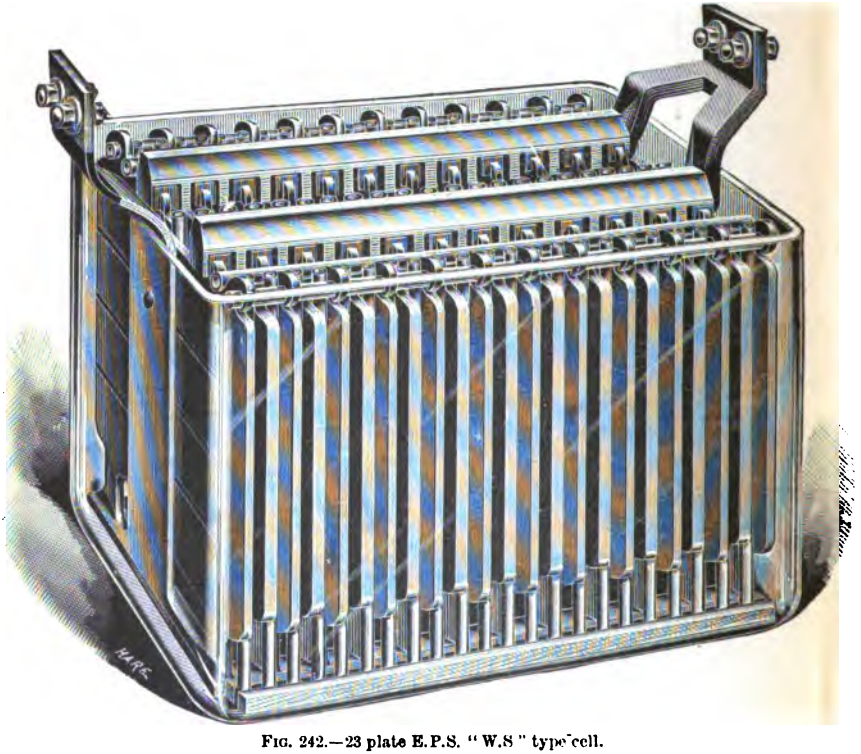


Fig. 242.—23 plate E.P.S. "W.S" type cell.

oblong grooves have parallel sides and extend to a depth of about $\frac{1}{16}$ inch upon either side, thus leaving $\frac{1}{8}$ inch for the central web of the plate.

The negative grid (Figs. 247, 248, 249 and 250) is $\frac{3}{16}$ inch thick. At intervals of an inch four stout ribs extend from the top to the bottom of the plate. Four horizontal ribs are spaced at unequal intervals together with two

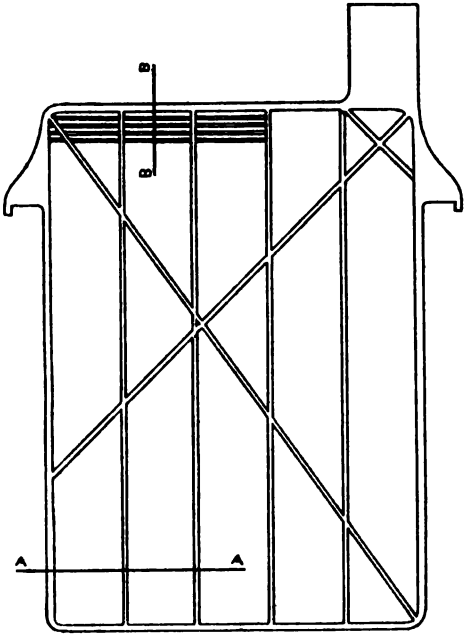


FIG. 243.—Hart positive. ½ full size.

FIG. 244.—½ full size section on line B B in Fig. 243.

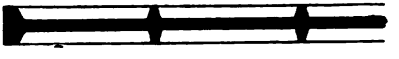


FIG. 245.—½ full size section on line A A in Fig. 243.

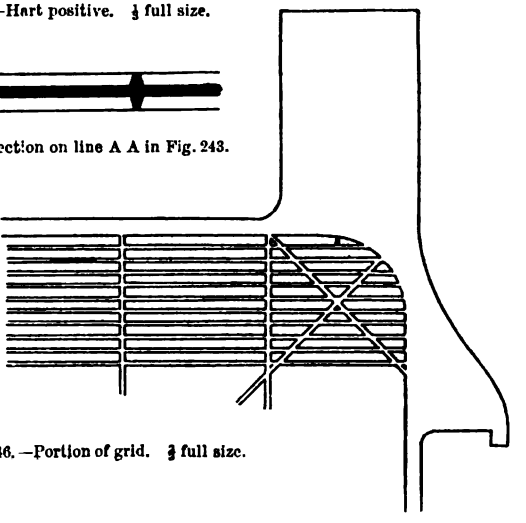


FIG. 246.—Portion of grid. ½ full size.

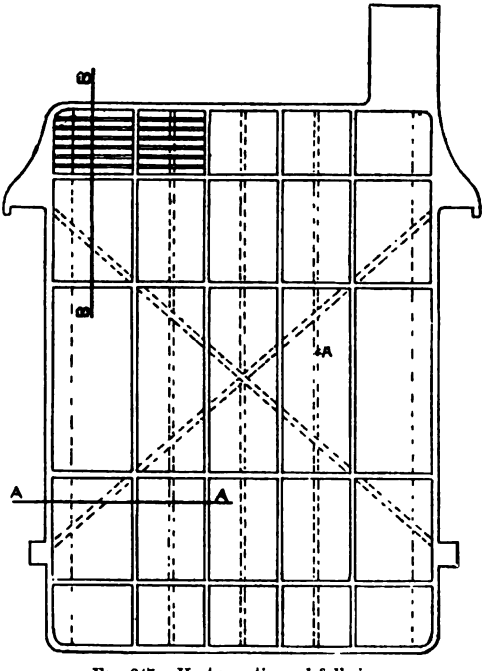


FIG. 247.—Hart negative. ½ full size.

FIG. 248.—¾ full size section on line B B in Fig. 247.

FIG. 249.—¾ full size section on line A A.

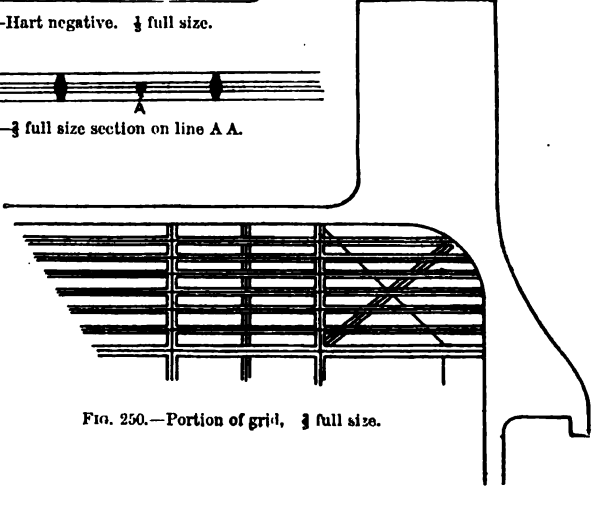


FIG. 250.—Portion of grid, ¾ full size.

crossing ribs, which, however, only extend through half the thickness of the plate. Between the four vertical are placed three finer ribs of the same thickness as the crossing ribs. The holes are parallel sides but have a somewhat "raggy" centre.

The general appearance of the Hart cell is illustrated in Fig. 251, from which it will be seen that the plates are of the hanging type supported upon two glass slabs by pro-

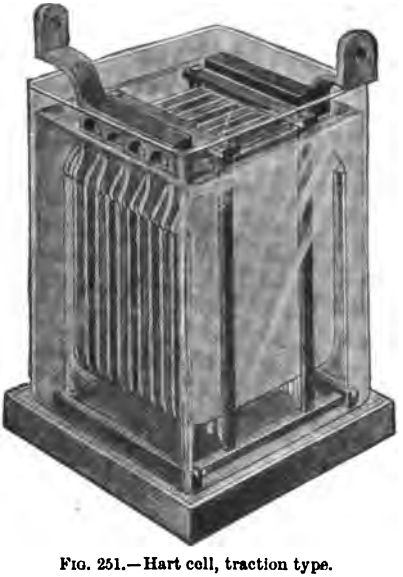


FIG. 251.—Hart cell, traction type.

jecting side lugs, the glass slabs resting in grooves cut in the wooden bottom block. This bottom block is combined with a teak frame having removable top pieces, the section being placed in between the four uprights, and the top afterwards placed in position. In this way the plates are thoroughly supported, so that the probability of buckling is comparatively remote. The separators employed are usually of the flanged glass tube type, but in the case of cells supplied to the Post Office ebonite separators are used.

The cells have a capacity of 49 ampere hours per positive

at the nine hour rate, whilst at the five hour or maximum rate it is 40 ampere hours.

The specific gravity of the electrolyte is 1·190 when placed in the cells, and when fully charged it should rise to 1·200. The discharge should cease immediately the gravity falls to 1·170.

The cell illustrated in Fig. 251 is of the T 11-plate type while the largest cell used by the Post Office has but nine plates. The 45, 72, and 90 ampere hour sizes of cell have respectively five, seven and nine plates, each $5\frac{1}{2} \times 7\frac{1}{2}$ inches. In the case of the 18 and 27 ampere hour cells which are specially made for the Post Office, the plates are 4×4 inches only and are supported directly upon the sides of the glass cell—otherwise they are similar to the type already considered.

E.M.F. on Charge and Discharge.

For charging secondary cells the E.M.F. of the dynamo should be from 2·6 to 2·75 volts per cell. The opposing E.M.F. of the battery rises to about 2·5 volts per cell at the end of the charge, but upon disconnecting the dynamo the E.M.F. at once falls to rather less than 2·2 volts—in fact the practical maximum should be regarded as 2·1 volts. During the greater part of the discharge the E.M.F. very closely approximates to 2 volts, and it is only towards the end of the discharge that it falls below this value. After 1·8 volts is reached the E.M.F. falls rapidly, and if the discharge is continued serious injury to the plates will probably result.

Internal Resistance and Temperature.

The internal resistance of even the smallest type of secondary cell is extremely low. In the E.P.S. K 7 type it is about ·0015$^{\omega}$, whilst in the Chloride R 15-plate type it is but ·00038$^{\omega}$. It is interesting to notice that the internal resistance of the cell decreases as the value of the discharge current rises. The resistance of dilute sulphuric acid is least when the acid is 30% and water 70%, or specific gravity 1·224. With 10% acid the resistivity is 67% higher and 84% higher with 60% acid.

The temperature at which the cell is working also affects

the E.M.F., specific gravity, and capacity of a cell. The higher the temperature at which the cell is working, the greater the capacity, but working at an abnormally high temperature will seriously reduce the life of the elements.

Insulators.

The cells are invariably placed upon shallow wooden trays filled with sawdust, so as to evenly distribute the weight of the cell and avoid the risk of breakage due to unequal stresses upon the bottom of the glass box.

The racks are usually formed of stout beams of timber with mushroom insulators upon which the trays are placed. The insulator (Fig. 252) consists of two glass castings fitted as shown, but with the lower part partially filled

Fig. 252.—Appearance and section of an insulator.

with oil. This prevents the formation of a continuous layer of moisture between the cell and the support, so long as the surface of the oil is free from dirt.

Electrolyte.

Brimstone sulphuric acid having a specific gravity of 1·840 should always be used. The acid should be free from impurities, such as arsenic, nitric, or hydrochloric acid. It should be diluted to the required extent with pure water—preferably distilled. If the water to be used is not soft and free from lime it should be boiled prior to use.

First Charge.

In erecting a new set of cells the acid should, upon no account, be put into the cells until everything is in readiness for commencing to charge. This first charge should preferably continue without intermission for from 36 to

40 hours—in some cases even longer. If it is not possible to arrange this the charge may be stopped after 12 to 18 hours, but current must not be taken from the cells. It will be found that the specific gravity of the electrolyte begins to fall immediately it is placed in the cells, and the first charge is continued until the gravity rises to its full value, and both plates gas freely whilst the solution attains a "milky" appearance. The charging rate for the first 12 hours is usually about one-half the maximum rate. After this period it is increased to the full rate, but, should the negatives fail to gas freely whilst positives do so, or *vice versa*, the charging rate is again cut down until this comes right.

Treatment of Cells.

Daily tests of the specific gravity and E.M.F. of each cell should be taken and recorded in order that any irregularities may be promptly investigated. It is essential that the maximum discharge current which is stated by each maker for the type of cell employed shall not be exceeded. It is equally necessary that the charging rate shall not be below or above the limits specified. It may, however, be stated that where a rapid charge is essential the maximum rate may be exceeded by from 20% to 30% for the major portion of the charge, provided that the current is cut down to the normal immediately the cells commence to gas. The cells must be removed from discharge immediately the E.M.F. per cell falls to 1·8 volts, or the gravity is less than the figures specified. If it is necessary to put the cells out of action they should be fully charged, and given a periodical charge of short duration every fortnight or so.

If these precautions are neglected "sulphating" occurs. This is the technical term used to denote the formation of higher sulphates upon the positives. It is at once apparent on account of the light colour of the patches. It may usually be rectified by long continued charges at about half the maximum charging rate. This will, in time, reduce the sulphate to the normal condition, but the process is long and tedious, and is one which, with proper care, should seldom, if ever, be necessary with a well-designed cell. It may be said that serious risk is involved whenever the charging or discharging rates are exceeded

or where the discharge is prolonged so that the voltage falls to less than 1·8 volts per cell.

In the event of buckling the solution should be drawn off and the plates straightened between a pair of boards. The negatives especially should not be left in the air any longer than is absolutely necessary, owing to the oxidation of the spongy lead which at once commences. Preferably, they should be placed in dilute acid whilst the positives are being attended to.

CHAPTER XV

THE UNIVERSAL BATTERY SYSTEM.

THEORY AND POWER ARRANGEMENTS.

Introductory.

THE provision of separate batteries for each circuit, in a large telegraph office, necessitates the employment of a vast number of cells, which, besides occupying a considerable amount of space, prove most costly to maintain. In fact it may be said that the provision of electrical energy by means of primary batteries is one of the most costly methods which can possibly be employed. Considerable economy may be effected by using a single set of primary cells to work a number of circuits, but, even then, the cost is several times that of energy obtained either from the town electric light mains or from the office lighting plant.

Secondary cells present notable advantages for the work of supplying energy to a number of telegraph circuits, and the system is being rapidly extended to offices of comparatively small magnitude. In addition to the economy obtained there is the advantage of greater constancy of E.M.F., which necessarily makes for the better working of the circuits concerned.

The use of a universal battery entails a considerable number of alterations in the connections of the circuits, whilst the use of a source of energy capable of supplying large currents renders precautions against fire imperatively necessary. Again, the cells are necessarily duplicated, at least in part, in order to provide for re-charging when necessary.

General Principle.

The general principle of the system will readily be

apprehended by considering three single current sounders worked by a common or universal main battery. The skeleton connections of three such circuits are depicted in Fig. 253, from which it will be seen that the positive pole of the earthed battery is "teed" off to the front stops of the three single current keys. The receiving apparatus at *A* and the sending apparatus at the distant ends of the

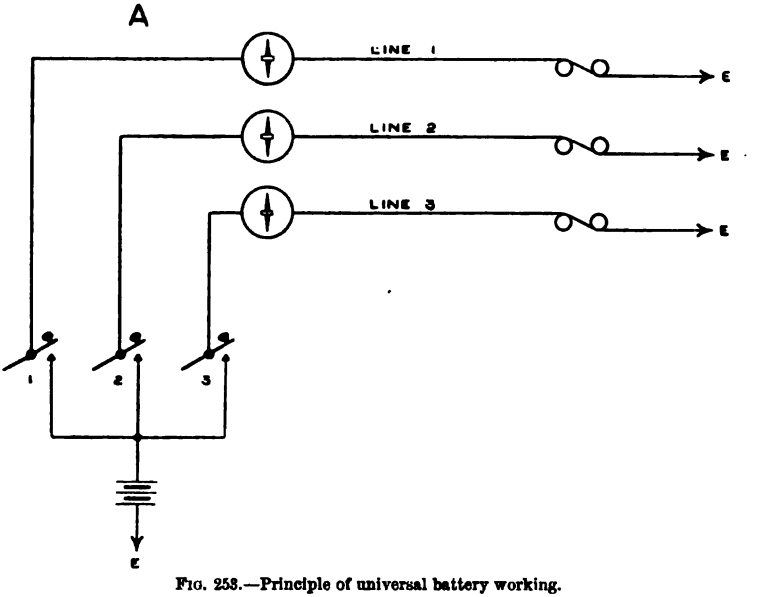


FIG. 253.—Principle of universal battery working.

circuits have been omitted, whilst the distant receiving apparatus is conventionally depicted.

If any one key is depressed a current, equal in value to the E.M.F. of the battery divided by the *total* resistance of the circuit, flows over the line in connection with it. If all the keys are depressed the current divides between the three circuits in inverse proportion to their respective resistances. The battery is then supplying current to lines 1, 2 and 3 in parallel, and the value of the current in each circuit depends upon the resistances of the three circuits, and the internal resistance and E.M.F. of the

battery. It will, later, be shown how these quantities must be related to each other to ensure satisfactory working, but before going further it is necessary to show that all circuits may be simplified to the general form just considered.

A single battery with its negative pole permanently earthed would, as has been seen, readily serve to work a number of single current sounders if all were up stations. If, however, down stations were also required to be worked, a second set of cells with the positive pole earthed would be essential. For single needle, double plate sounder, and

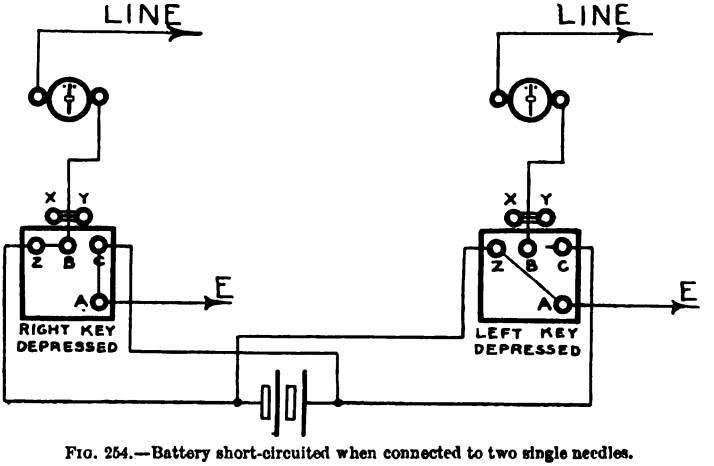


FIG. 254.—Battery short-circuited when connected to two single needles.

double current circuits, two batteries would necessarily be required, one of which would supply positive and the other negative currents. In order to make this point quite clear let two "up" single needles be connected to one battery as depicted in Fig. 254. When the right-hand station depresses the right key and the other station depresses the left key both poles of the common battery are earthed, thus forming a short circuit and so preventing either station from sending out a current. Similarly, had one of the stations been up and the other down the same result would have occurred when both right or both left keys were simultaneously depressed.

It will, therefore, be obvious that every form of apparatus which requires to send out currents in both directions must be provided with two batteries having opposite poles put to earth. The one battery is connected to line by one position of the key or keys whilst the other is similarly connected when the position of the key or keys is changed. For example, a single needle up station will require to connect the negative battery to line when the left key is depressed, whilst the positive battery will be similarly connected upon depression of the right key. This necessitates alterations in the commutator connections, but essentially the arrangement reduces itself as regards the sending circuit to the conditions of Fig. 253, but with a second key for each line connected to the negative battery.

If, therefore, the theory of the system is considered from the point of view of Fig. 253 it will be evident that the essential conditions involved have been satisfactorily dealt with.

Theory of System.

When a single primary battery is employed to work several circuits the value of the current in each varies in accordance with the number of keys which are simultaneously depressed. If this variation of current is large the working is unreliable, and it is therefore essential that the conditions which must be fulfilled to prevent this should be clearly apprehended. If ten single current circuits each having a resistance of 1000$^{\omega}$ are connected to a single battery, having an E.M.F. of 25 volts and an internal resistance of 100$^{\omega}$, the current flowing through each circuit when all the keys are depressed is—

$$\tfrac{1}{10} \text{ of } \frac{25}{100 + \frac{1000}{10}} = 12{\cdot}5 \text{ m.a.}$$

If but one key is depressed, the value of the current in that circuit is—

$$\frac{25}{100 + 1000} = 22{\cdot}7 \text{ m.a. approx.}$$

It will therefore be evident that the current in any of

the circuits will vary between 12·5 m.a. and 22·7 m.a. according to the number of keys which happen to be simultaneously depressed. This represents a variation of 55%, which would, of course, render satisfactory working quite impossible.*

It will now be well to consider the battery replaced by one of the same E.M.F. but having absolutely no internal resistance. In this case the current in each circuit is always 25 m.a. no matter whether this is the only circuit having its key depressed or whether all the keys are simultaneously depressed.

In the latter case the joint resistance of the 10 circuits is is 100Ω and the total current sent out by the battery is 250 m.a., but this divides equally between them, thus giving 25 m.a. in each. When one key is depressed the resistance which the battery encounters is 1000Ω and the current is therefore 25 m.a. as in the previous case. In other words, the circuits have absolutely no effect upon each other, and this represents the ideal condition.

* The following formulæ, which may be readily deduced, are frequently useful.

Let a = resistance of one of a number of circuits, which may be of unequal resistance, connected to a universal battery.

R_1 = joint resistance of all the circuits connected to the battery.

p = current in circuit of $a\Omega$ resistance when all the circuits are working expressed as the percentage of the current in a when it only is working.

r = internal resistance of battery.

$$p = 100 \left\{ \frac{1 + \frac{r}{a}}{1 + \frac{r}{R_1}} \right\}$$

Where the circuits are of equal resistance R and the number connected is n—

$$p = 100 \left\{ \frac{R + r}{R + nr} \right\}$$

If p, R and r are specified, the number of circuits n which may be connected is—

$$n = \frac{\frac{100}{p}(R + r) - R}{r}$$

If p, R and n are fixed, r must not exceed

$$r = \frac{R(100 - p)}{pn - 100}$$

The internal resistance of even the smallest form of secondary may be considered quite negligible in comparison with the resistances met with in ordinary telegraph practice, and therefore the size of the cell chosen depends solely upon the quantity of energy required for a given period. If the cells were too small it might be necessary to charge them two or three times a day, whereas the general practice is every fourth day.

Universal Working with Primary Batteries.

When primary cells are used to form a universal battery the internal resistance is of vital importance, and its value for satisfactory working must never exceed half the joint resistance of all the circuits connected to it. In general not more than five or six circuits are connected to a primary cell universal battery. Moreover the resistances of the circuits connected should not differ by more than 25%. Should this case arise resistance blocks are inserted in the battery leads to the instrument. The resistance inserted should, however, only be of sufficient value to bring up the resistance of the circuit to within 25% of that of the highest circuit connected.

Before passing on to the consideration of the various arrangements it will be necessary to consider voltmeters and ammeters, since these instruments are essential adjuncts to the secondary cell systems.

Voltmeter.

A voltmeter consists essentially of a galvanometer wound to a high resistance and with its scale marked to read in volts direct. By referring back to page 128 it will be seen that the deflection upon a high resistance galvanometer is proportional to the E.M.F. of the cell connected to it. This equally applies to any other source of E.M.F. provided the external resistance is large in comparison with the internal. Therefore the scale of the instrument may at once be marked in volts for direct reading. The important difference between an ordinary galvanometer and a voltmeter is that in the former case a standard cell is necessary for obtaining the constant, and that the

instrument's deflections cannot be relied upon to always mean the same value without actual testing.

A voltmeter may then be defined as an instrument reading directly in volts, but whose constant does not change.

One type of instrument used by the Post Office is known as the "Weston," and consists of a D'Arsonval galvanometer with an aluminium pointer controlled by the moving coil and two flat spiral hair-springs. These springs which oppose the motion of the coil are of non-magnetic material, and are placed in front and at the end of the pivoted moving coil. They also serve the purpose of connecting

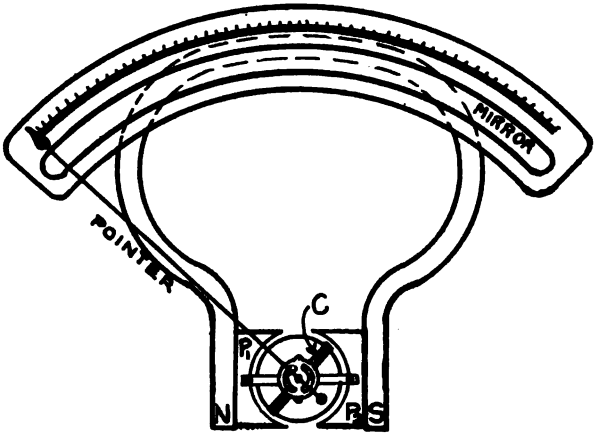


FIG. 255.—Weston voltmeter.

the ends of the coil to the stationary terminals of the instrument. The general arrangement of the instrument is shown in Fig. 255. The curved wrought iron pole and centre pieces ensure a uniform magnetic field and thus render the scale uniform.

The scale of the voltmeter is marked from 0 to 15 volts, but by using a resistance coil in series the divisions read exactly ten times these values, *i.e.* from 0 to 150 volts. The resistance of the instrument is 1677·5$^{\omega}$ for 15 volts, 16775$^{\omega}$ when reading up to 150 volts.

Ammeters.

Ammeters are employed for regulating the charging current passing through the cells and for observing the values of the current passing over the various main leads. Like the voltmeter, the ammeter must be of such construction as to ensure that the constant does not change. Its resistance must, however, be as small as possible since it is connected in the main circuit. The form used by the Post Office consists of a low resistance, termed the ammeter shunt, and an instrument precisely similar to the voltmeter but wound to a much lower resistance. The current passing through the shunt (Fig. 256) creates a difference of potential between its terminals, the value of which is proportional to the value of the current passing. The instrument's deflections are proportional to the differences of potential between the ends of the shunt and so to the current flowing. The scale is marked in amperes, and like the voltmeter scale the divisions are all of uniform length. The resistance of the arrangement for reading up to 50 amperes is about ·00435ω at 70° F.

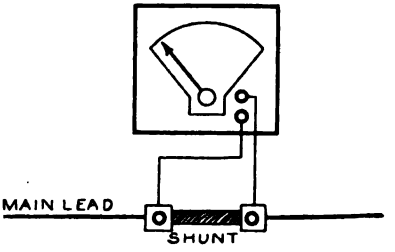


Fig. 256.—Ammeter.

It should be pointed out that by using a number of shunts and a very simple form of switch the value of the current can be measured at several points with a single instrument. This principle is largely employed in connection with the power arrangements of the Common Battery telephone system.

Voltages Required.

The values of the E.M.F.s required to work all the circuits in a large telegraph office differ very considerably, but it has been found that practically the whole of the conditions are met by providing four positive and four negative values. The values are in both cases:—

24ᵛ, 40ᵛ, 80ᵛ, 120ᵛ.

24-Volt Sets.

The installation of secondary cells may be divided into two distinct groups, respectively termed the "main" and "24-volt" batteries. The latter, which will be considered first, is used to work the local circuits and to provide main battery power for all the sub-office or other minor circuits for which 24 volts is sufficient. Since these circuits are usually more numerous than longer ones, and the battery also provides current for all local circuits, a larger type of cell than is employed upon the main sets is frequently required. For these reasons the 24^{v} battery is always kept separate and distinct from the main sets which provide 40^{v}, 80^{v}, and 120^{v}.

In order to provide for the re-charging of the cells, and also to ensure a stand-by in case of failure or accident, the battery is provided in duplicate. The 24^{v} set therefore consists of 48 cells or four groups of 12 cells, thus providing 24^{v} positive and negative and two groups spare.

Necessity for 900$^{\omega}$ Sounders.

With 20$^{\omega}$ sounders difficulty is experienced in keeping the resistance of the battery and leads to the point at which the current divides sufficiently low for satisfactory working. For instance, the variation in current is 25% between one circuit and 100 circuits simultaneously working when the resistance of the battery circuit is only ·07$^{\omega}$. In order to avoid the necessity for such inconveniently low values all local apparatus (*e.g.* sounders, double plate sounders, uprighters, etc.) is wound to a resistance of 1000$^{\omega}$ with a 9000$^{\omega}$ shunt, thus giving a joint resistance of 900$^{\omega}$. Under similar conditions the current variation would be 25% with a battery resistance of approximately 3$^{\omega}$, a value which would never be reached under the worst possible conditions.

The power required to work any 900$^{\omega}$ local is 24 volts, and therefore the circuits are divided into approximately equal groups, the one group being worked by the positive and the other by the negative 24^{v} battery.

Main Sets.

The main battery consists of eight groups of 20 cells

each, two groups of which are always spare. The complete installation is shown diagrammatically in Fig. 257. It is important to notice that the groups of cells will not be worked evenly since the last sets of cells forming the 120^{v} lead are only called upon to supply current for the circuits requiring that E.M.F., whereas the inner sets supply all circuits requiring 40^{v} and, in addition, provide current for those requiring 80^{v} and 120^{v}. The groups providing 40^{v} are therefore worked more heavily than those providing 80^{v} or 120^{v}, and similarly the groups providing 80^{v} are more heavily worked than those providing 120^{v}. Hence inner cells would become discharged before the outer

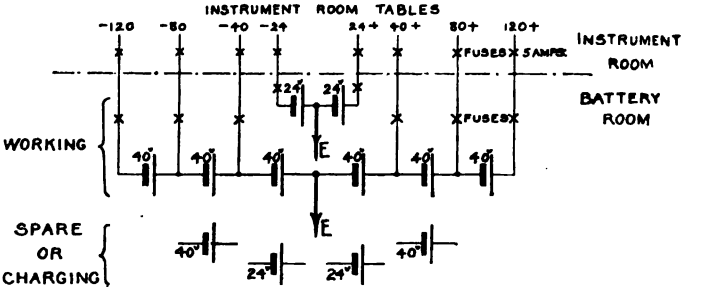


FIG. 257.—Complete installation of secondary cells.

ones. In order to secure greater uniformity in output a somewhat complex switch has been devised to change the positions of the groups. For the first day No. 4 set supplies 40^{v}, for the second 80^{v}, for the third 120^{v}, whilst upon the fourth day it is being charged.

Two switches are employed, one of which deals with the positive and the other with the negative groups. Each switch has four positions corresponding with the four ways in which the cells may be joined up. The connections formed in each position of the negative switch are shown in Fig. 258. The positive switch is similarly arranged, and a sketch of the skeleton connections would be merely a repetition of the last figure. The arrangement will be quite apparent from the comparison of Figs. 257 and 258 with the table given upon the subsequent page.

TABLE SHOWING CONNECTIONS OF THE MAIN SETS.

Negative sets.					Positive sets.				
Position of switch.	No. of set connected to				Position of switch.	No. of set connected to			
	On charge.	120v.	80v.	40v.		40v.	80v.	120v.	On charge.
No. 1 1st day	1	2	3	4	No. 1 1st day	4	3	2	1
No. 2 2nd day	2	3	4	1	No. 2 2nd day	1	4	3	2
No. 3 3rd day	3	4	1	2	No. 3 3rd day	2	1	4	3
No. 4 4th day	4	1	2	3	No. 4 4th day	3	2	1	4

GENERAL SCHEME OF FUSES.

The use of secondary cells entails the provision of fuses, since large currents may readily result from the presence of faults. These excessive currents may seriously injure the cells and also might quite easily produce a fire were precautions not taken to prevent the continuous passage of current of abnormal value. A 20-ampere fuse is inserted at the cells in the leads to the "switch cabinet," and 5-ampere fuses are placed in the leads at the "main distributing cabinet" in the instrument room. After passing these fuses the leads go to the various "distribution and fuse cases" upon the tables. At these points 1-ampere glass tube fuses are inserted between the main leads and the instruments themselves. Every instrument is represented by a fuse upon this case, and it is therefore impossible for a fault upon one instrument to blow a main fuse and thus temporarily stop the working of every circuit using the voltage in question. The general scheme is sufficiently indicated in Fig. 259.

BATTERY ROOM.

The battery room should be fairly large and well

ventilated, owing to the acid spray which pervades the atmosphere whilst charging is proceeding. The cells are carried upon the trays and insulators described in the previous chapter, resting upon pitch-pine racks. These

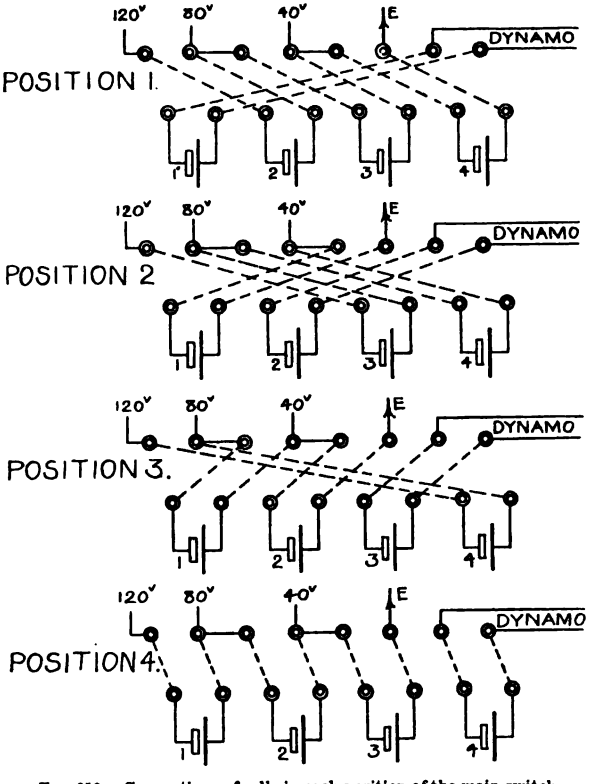


FIG. 258.—Connections of cells in each position of the main switch.

racks should be so placed that the cells can be inspected from both sides. The floor of the room is covered with sheet lead, the various seams in which are burnt, and *not* soldered, together.

The ideal method of connecting the cells together is by lead burning, so dispensing with bolted connections. The

disadvantage is that to remove a cell entails cutting the connections. In telephone installations, where the battery is used to provide "speaking" power, the connections between the cells are invariably burnt together, but for telegraphic purposes the same need for keeping the resistance of the battery down to the lowest possible limit does not exist. The Hart Company provide a bolt and nut made of a lead alloy which is not affected by the acid spray. Other makers employ brass nuts and bolts, and

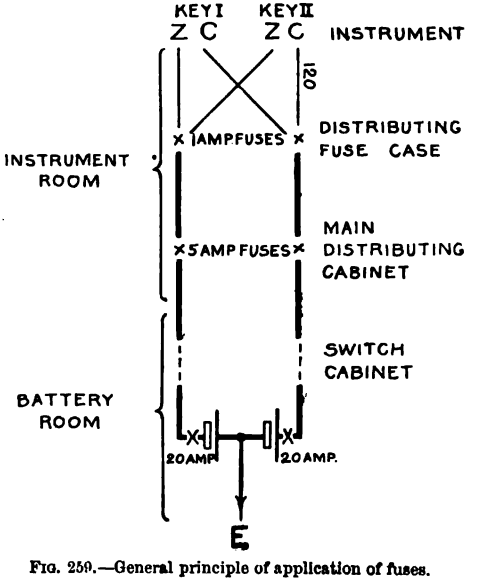


FIG. 259.—General principle of application of fuses.

trust to the layer of acid-resisting paint with which they are covered for protection.

MAIN FUSES AT THE CELLS.

The leads are taken from the cells to a grooved casing running along the side of the racks, but before entering the casing a fuse is inserted. This fuse consists of a circular fibre tube with a suitable slot to give access to the fuse wire, which is of silver. The cables are seven strands

of No. 16 copper wire, insulated with paper, impregnated with resin oil, and covered with a seamless sheathing of lead. The cable is connected to the fuse by means of a thimble connector and a brass sleeve, the latter being soldered on to the lead covering of the cable as illustrated in Fig. 260.

FIG. 260.—Method of terminating cables and fuse at the cell.

SWITCH CABINET.

From the cells the leads pass on to the switch cabinet, which is also placed in the battery room. Dealing with the 24-volt sets first, it will be seen (Fig. 261) that the leads pass to the centre of points of four double-pole two-way switches. With the switches in the positions shown sets 1 and 3 are connected to the 24^{v} leads to the instrument room with the junction of the sets earthed, whilst sets 2 and 4 are connected in series to the dynamo through the 48^{v} charging switch (Fig. 262). Sets 1 and 2, which provide the negative voltage, are interchangeable, as are sets 3 and 4 positive voltage, and therefore the following combinations are possible :—

Sets 1	and 3	working.	2 and 4 charging.
,, 1	and 4	,,	2 and 3 ,,
,, 2	and 3	,,	1 and 4 ,,
,, 2	and 4	,,	1 and 3 ,,

DETAILS OF POSITIVE AND NEGATIVE SWITCHES.

The positive and negative main switches are of a far more complicated character, since three-fourths of the cells are working whilst the remaining fourth is spare or is being charged. Moreover, arrangements have been made so that whilst the switches are being moved the power is never cut off from the instrument room. This is effected by placing two sets in parallel on to the various main leads until the set of cells to be charged is in parallel with the last set, when it is moved on to the charging leads. The connections of the

positive and negative switches are identical, and the latter is illustrated diagrammatically in Fig. 263.

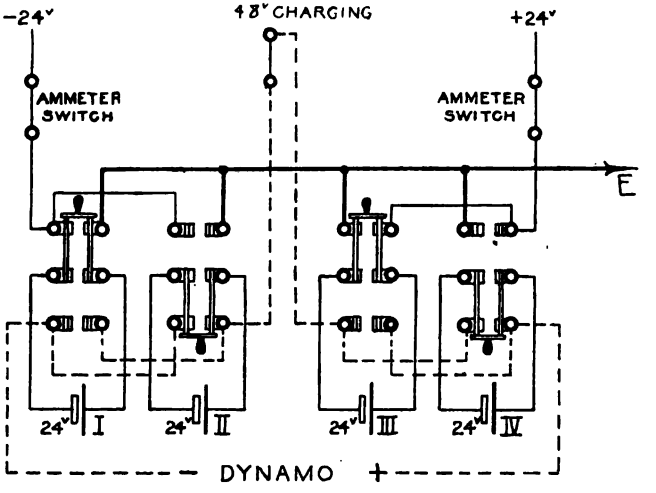


Fig. 261.—24v battery switches.

The switch consists of a commutator barrel upon which are placed eight continuous rings connected to the various members of the eight rings of segmental blades bearing similar numbers to those of the continuous rings. Upon the drums two sets of eight brushes, connected as shown, make contact with the segmental blades. The commutator is revolved to make the various changes whilst the brushes are stationary. The main switches are operated by means of a removable handle (not shown in Fig. 265) upon the side of the cabinet. From Fig. 263 the various changes may readily be traced, but in order to render the arrangement quite clear, the following note of the various changes is appended :—

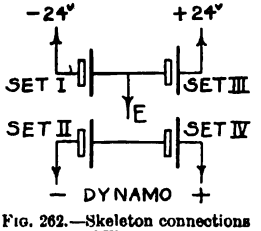


Fig. 262.—Skeleton connections of Fig. 261.

FOUR POSITIONS OF SWITCH.

Position I. = 1 to G, 3 to A, 5 to C, and 7 to E.

First Move after 10°	1	Breaks	from	——	——	G	
,, 20°	1	——	——	makes	on		E
,, 30°	7	,,	,,	——	——	E	
,, 40°	7	——	——	,,	,,		C
,, 50°	5	,,	,,	——	——	C	
,, 60°	5	——	——	,,	,,		A
,, 70°	3	,,	,,	——	——	A	
,, 80°	3	——	——	,,	,,		G

Position II.—at 90° = 1 to E, 3 to G, 5 to A and 7 to C.

Second Move after 100°	3	Breaks	from	——	——	G	
,, 110°	3	——	——	makes	on		E
,, 120°	1	,,	,,	——	——	E	
,, 130°	1	——	——	,,	,,		C
,, 140°	7	,,	,,	——	——	C	
,, 150°	7	——	——	,,	,,		A
,, 160°	5	,,	,,	——	——	A	
,, 170°	5	——	——	,,	,,		G

Position III.—at 180° = 1 to C, 3 to E, 5 to G and 7 to A.

Third Move after 190°	5	Breaks	from	——	——	G	
,, 200°	5	——	——	makes	on		E
,, 210°	3	,,	,,	——	——	E	
,, 220°	3	——	——	,,	,,		C
,, 230°	1	,,	,,	——	——	C	
,, 240°	1	——	——	,,	,,		A
,, 250°	7	,,	,,	——	——	A	
,, 260°	7	——	——	,,	,,		G

Position IV.—at 270° = 1 to A, 3 to C, 5 to E and 7 to G.

Fourth Move after 280°	7	Breaks	from	——	——	G	
,, 290°	7	——	——	makes	on		E
,, 300°	5	,,	,,	——	——	E	
,, 310°	5	——	——	,,	,,		C
,, 320°	3	,,	,,	——	——	C	
,, 330°	3	——	——	,,	,,		A
,, 340°	1	,,	,,	——	——	A	
,, 350°	1	——	——	,,	,,		G

MAIN CHARGING SWITCHES.

The main charging switches and the general arrange-

ment of the positive and negative main switches are shown in Fig. 264. The dotted connections between the cells and the main leads to the instrument room show the main positive and negative switches each in the fourth position, but these connections are as shown in Fig. 258 if the switches occupy any one of the three other positions.

The charging leads pass through the two double-pole switches (one for the positive and one for the negative main sets) through an adjustable resistance on to the positive and negative main switches. Finally, in series with each set of cells a single-pole switch is inserted.

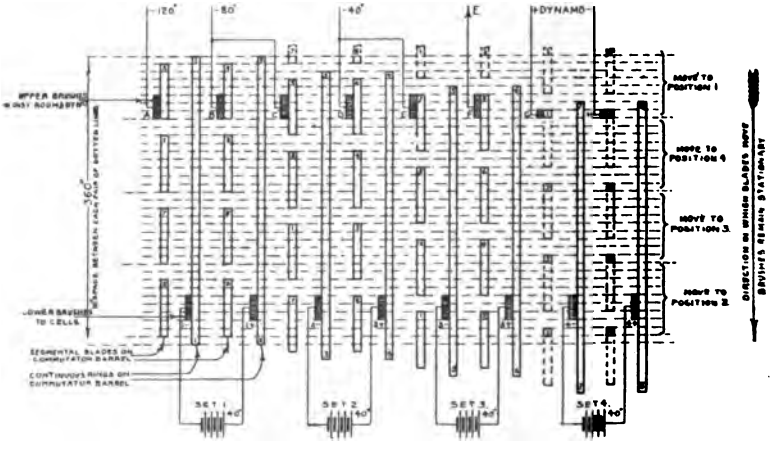


FIG. 263.—Connections of the drum switch for the negative main sets.

The resistance mentioned is of bare wire and may be connected up so as to give resistances of $\frac{2}{3}^{\omega}$, 1^{ω} and $1\frac{1}{3}^{\omega}$, and enable the 40^{v} sets to be charged in parallel with two 24^{v} sets. The object of the resistance is solely to take up the difference of 8^{v} which exists between the E.M.F.s of the sets.

The general appearance and arrangement of the switch cabinet is indicated in Fig. 265.

MAIN DISTRIBUTING CABINET.

From the switch cabinet the leads pass to the main

distributing cabinet in the instrument room. Here the leads pass through U-links and 5-ampere fuses of the same type as those illustrated in Fig. 260, but with a finer wire. A voltmeter is also provided for testing purposes,

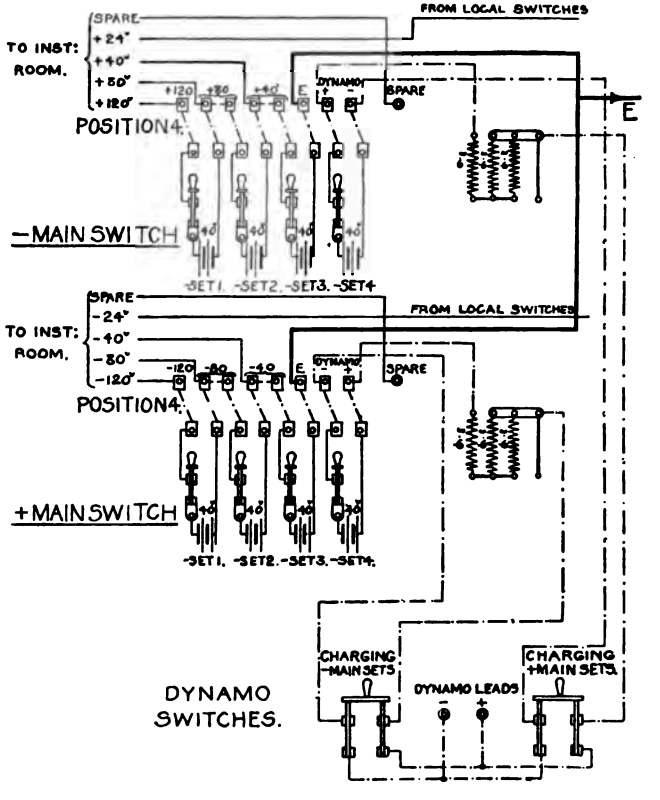


FIG. 264.—Main charging switches

and is placed within the cabinet behind the glass door. The general appearance and arrangement of the cabinet will readily be perceived from Fig. 266.

There is space for two additional leads beyond 120v,

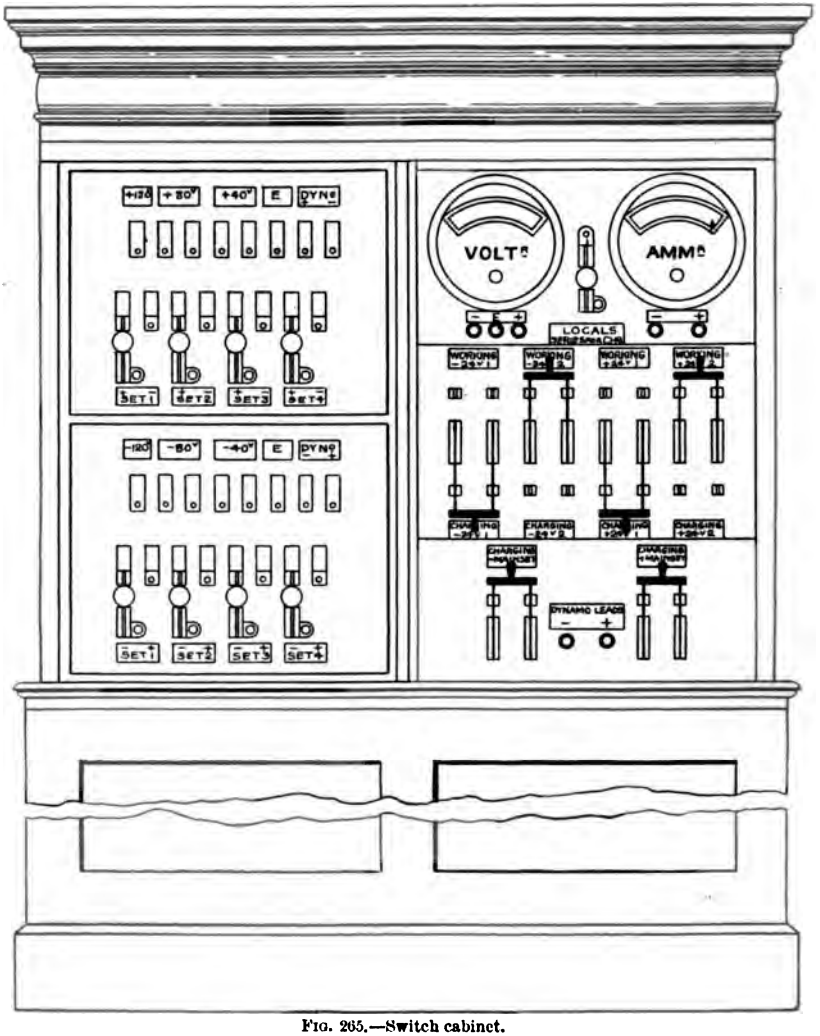


Fig. 265.—Switch cabinet.

and these voltages when required are formed by adding

ordinary bichromate cells until the required voltage is obtained. The cases are, however, so few that the provision of secondary cells is not warranted.

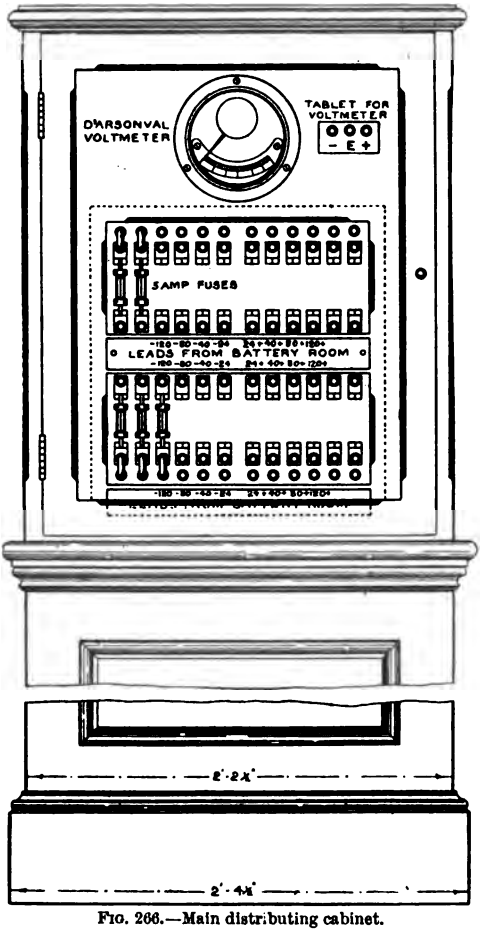


FIG. 266.—Main distributing cabinet.

The cabinet illustrated provides for two separate sets of leads to the tables, and thus enables the office to be divided into two halves. In very large offices the division

is sometimes carried further, and more than two tablets are provided, whilst for small offices but half the provision shown is required, and a single set of leads run round the whole of the instrument room.

Distribution and Fuse Case.

A distribution and fuse case is provided for every three tables, and is placed upon the end of the central table, but with the front in the opposite direction to the front of the instruments. The power leads are tapped off below the floor-line, and are carried to the case in an iron troughing. The power lead is bared by removing the lead sheathing, and impregnated paper and a similarly stripped length of cable is then soldered on to the power lead; the whole is then carefully insulated and covered by a shaped piece of lead sheet securely soldered so as to form an air and water tight joint.

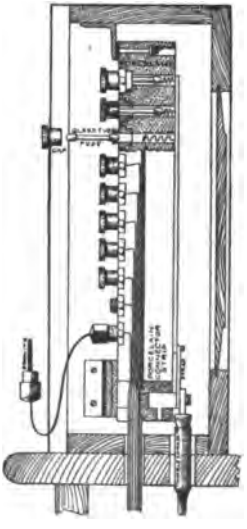


Fig. 267.—Section of distribution and fuse case.

The tablet (Figs. 267 and 268) provides for 80 fuses—*i. e.* ten for each voltage, but by altering the connecting straps which normally join the power leads through to the cut-out strips from the vertical to the horizontal position, sufficient flexibility is obtained to meet all the possible requirements.

The base of the case is of porcelain, with suitable holes for the insertion of the fuses. The brass strip which closes the back of each hole is connected to the particular voltage dealt with by the strip. Upon this strip a spiral spring (Fig. 267) is placed so as to press upon and make satisfactory contact with the end of the glass-tube fuse (see Chapter XVIII) which normally rests upon it. The other end of the fuse makes contact with the inner part of the screwed brass cap which normally holds it in position. The base on to which the cap screws is connected to the

instrument leads of the circuit to which it is attached, and thus a fuse is inserted in every lead from the case to the instruments. The fuses are of the usual glass-tube pattern, with 2-mil platinum wire which fuses at one ampere.

Under normal conditions the fuses are not visible, and to examine them it is necessary to remove the brass cap (which at once disconnects the power from the instrument) and remove the fuse.

Special cords are used for changing the power supplied

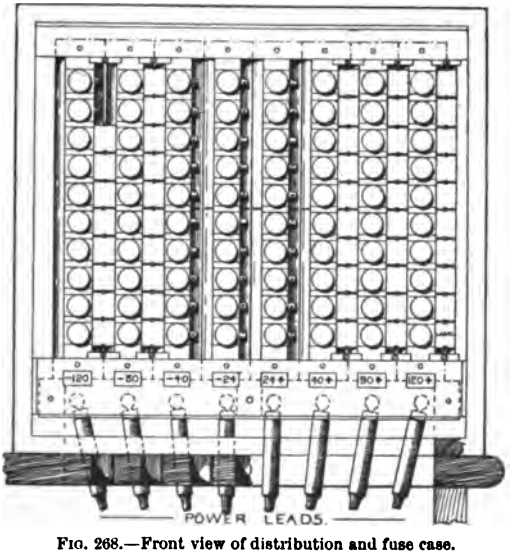


FIG. 268.—Front view of distribution and fuse case.

to a circuit having a fuse cap at one end and a fuse cap with an ebonite insulated connector at the other, the fuse cap and fuse are removed from the circuit in question, and their place is taken by the connector, the cap of which is screwed into position. The other end of the cord is then connected in the ordinary way to any spare position on the voltage required, a fuse being of course inserted at this point.

The leads from the fuse case to the instruments of the table upon which it stands are single india-rubber and cotton covered No. 20 copper wire, whilst those to the

adjoining tables, which necessarily pass beneath the floor in the iron troughing, are of similar description, but have a lead sheathing instead of the external braiding of cotton.

ORIGINAL SECONDARY CELL SYSTEM.

It will now perhaps be well to very briefly describe the older secondary cell system which is being superseded by that already considered. There are many of the old installations in existence, and therefore a brief general outline will probably prove useful at offices where the arrangement still exists.

The chief points of difference are that in the older system the main cells are duplicated in their entirety, and that the instrument fuses are placed at the instruments whilst a distributing case is provided at every table.

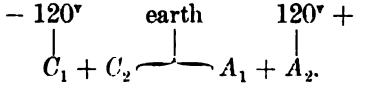
The voltages provided are the same as in the new arrangement save that a 60^{v} lead is also in use.

The 24^{v} battery is provided in duplicate, just as in the later system.

Main Switches.

The complete set of main cells is shown in Fig. 269. Each of the eight sets A_1, A_2, B_1, B_2, C_1, C_2, D_1 and D_2, consists of 30 cells; B_1, B_2, D_1, and D_2 being duplicates of A_1, A_2, C_1, and C_2 respectively. A_1 and C_1 each have 20 cells on the left and 10 on the right of the "tap" wire T, whilst A_2 and C_2 have 10 cells on the left and 20 on the right.

In order to give the cells approximately equal amounts of work a switch termed the "reverser" is employed. When the switch is raised the cells supplying the positive and negative voltages are reversed thus: C_1 and C_2 are connected to the negative, and A_1 and A_2 to the positive leads. The battery is then arranged thus—



For the sake of simplicity the intermediate voltages provided by the various "tap" wires have been omitted, but comparison with Fig. 269 will render the arrangement quite apparent.

To effect this change the switch makes the following crosses—

$A_1 - 40^v$ with $C_1 - 40^v$.
$A_1\ T$ with $C_1\ T$.
$A_1 + 20^v$ and $A_2 - 20^v$ with $C_1 + 20^v$ and $C_2 - 20^v$.
$A_2\ T$ with $C_2\ T$.
$A_2 + 40^v$ with $C_2 + 40^v$.
Also $A_1 - 40^v$ and $C_2 + 40^v$ are earthed in place of $A_2 + 40^v$ and $C_1 - 40^v$.

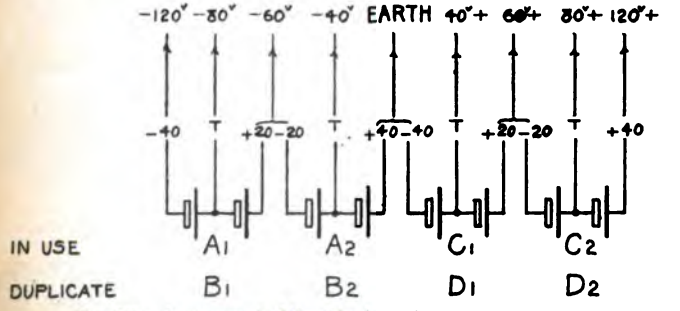


FIG. 269.—Arrangement of the older type of secondary cell plant.

The sets A_1 and A_2 are changed for the sets B_1 and B_2 by lowering the "A and B" switch lever, whilst C_1 and C_2 may be replaced by D_1 and D_2 by lowering the "C and D" switch lever. In fact the arrangement may be summarised as follows:—The positions of the "A and B" and "C and D" levers determine which set of cells is to be connected to the instrument room, whilst the reverser determines their relative positions.

The following table shows the disposition of the working cells in each position of A and B, C and D, and reverser levers:—

Position of Levers.			Battery supplying negative voltages.	Battery supplying positive voltages.
Main A or B.	Reverser.	Main C or D.		
Up	Down	Up	A	C
Up	Up	Up	C	A
Down	Down	Up	B	C
Down	Up	Up	C	B
Up	Down	Down	A	D
Up	Up	Down	D	A
Down	Down	Down	B	D
Down	Up	Down	D	B

The leads of the cells which are not in use are passed on to the "looping switch." In the upper position of this switch the cells are connected to the "looping" leads to the instrument room, whilst, in the lower position, they pass to the charging switches. These switches determine whether A_1 A_2, or both, *or* whether C_1 C_2, or both, are connected to the dynamo for charging when B and D sets are working. When A and C are working B_1, B_2, or both may be charged *or* D_1, D_2, or both, may be charged.

Distribution.

The leads from the cabinet to the main distributing cabinet were provided in duplicate, so that a faulty lead could at once be replaced or the second lead could be used whilst a fuse was being replaced in the first. Moreover fuses were inserted in the switch cabinet instead of at the cells. The duplication of the leads was found to be unnecessary, and it will, no doubt, have been noticed that this is not done in the case of the new arrangement. The distributing tablets placed upon each table have 45 test holes, 15 of which are connected to the main power leads only. Formerly arrangements were made for connecting the spare set of cells to the instrument room for working metallic circuits during the prevalence of earth currents, but the arrangement has been abandoned on account of the fact that two offices each having secondary cells cannot work in this way. The "looping" battery was not, of course, earthed at the centre, but was connected

to one line of the metallic circuit, the positive and negative leads being connected to the key in the ordinary way.

The test holes were connected by U-links as indicated in Figs. 270 and 271. The fuse box was joined up as shown

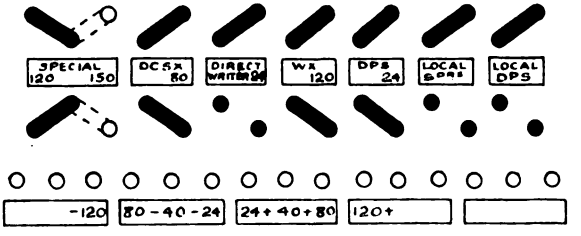


FIG. 270.—Distribution tablet fixed upon each table in the old type of installation.

and a common earth connection was not employed. The somewhat peculiar arrangement of the fuse box was adopted in order to prevent a fuse, wrongly inserted between two adjacent clips, from producing a short circuit without the intervention of a fuse.

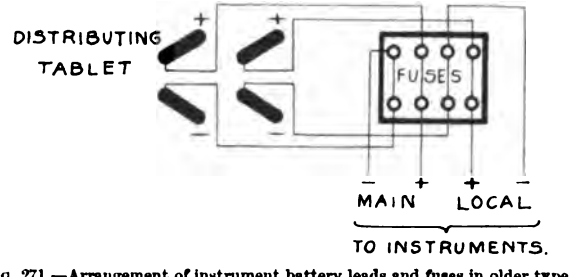


FIG. 271.—Arrangement of instrument battery leads and fuses in older type of installation.

CHARGING ARRANGEMENTS.

Before discussing the charging arrangements it is necessary to indicate how Ohm's law may be applied to a circuit consisting of a dynamo charging a battery of secondary cells. If the opposing E.M.F. of the cells is e volts whilst E is the

E.M.F. of the dynamo, and R the total resistance of the circuit, the resulting current C is obtained thus—

$$C = \frac{E - e}{R}$$

The opposing or back E.M.F. of the battery is 2·1 volts per cell at the beginning of the charge, whilst at the end it will have risen to 2·5 volts per cell.

Example.—It is required to charge 25 cells from a dynamo having an E.M.F. of 100^v and a resistance of ·02$^\omega$. If the charging current is to be maintained at 15 amperes what resistance must be inserted in the circuit at the beginning and at the end of the charge? The resistance per cell is ·0015$^\omega$ and the resistance of the leads ·02$^\omega$—

Internal resistance of cells .	·0015 × 25	= ·0375$^\omega$
Resistance of dynamo . . .		= ·02$^\omega$
Resistance of leads, fuses, etc.		= ·02$^\omega$
Total resistance of circuit. .		= ·0775$^\omega$

Back E.M.F. at beginning of charge = 2·1^v × 25 = 52·2^v
„ „ end „ „ = 2·5^v × 25 = 62·5^v

$$\text{Current} = \frac{\text{Charging E.M.F.} - \text{Back E.M.F.}}{\text{Total resistance}}$$

or

$$= \frac{\text{Effective E.M.F.}}{\text{Total resistance}}$$

At the beginning of the charge, effective E.M.F. = 100^v − 52·5^v = 47·5^v.

$$\frac{E}{C} = R \therefore \frac{47{\cdot}5}{15} = 3{\cdot}16^\omega$$

Resistance to be inserted at beginning of charge—

= 3·16 − ·0775$^\omega$ = 3·09$^\omega$ approx.

Similarly, at the end of the charge the resistance to be inserted = 2·45$^\omega$ approx.

Example.—It is required to charge two batteries of respectively 20 and 24 cells in parallel at 10 amperes each. What resistance will be required to be added to the smaller battery if the E.M.F. of the dynamo is 65^v?

Resistance of circuit of larger battery $= \frac{65 - 24 \times 2{\cdot}5}{10}$

$= {\cdot}5^{\omega}$

Resistance of circuit of smaller battery $= \frac{65 - 20 \times 2{\cdot}5}{10}$

$= 1{\cdot}5^{\omega}$

Additional resistance $= 1{\cdot}5 - {\cdot}5 = 1^{\omega}$

This problem illustrates the calculation of the resistance required to reduce the voltage applied to the main sets (see page 470).

Provision of Charging Current.

In a very small number of cases where the current required is very large it is economical to provide a separate engine and dynamo for charging the cells. Where the Post Office has an electric light plant the cells are usually charged from it, since the voltage most frequently needed is 60^{v} and that employed for lighting 100^{v} or thereabouts. If there is no office lighting plant current is taken from the town mains and is employed to charge the cells directly if continuous current and of suitable E.M.F. Where the supply is either alternating current or continuous current at a pressure of 200^{v} and over, motor-generators are employed. A motor-generator consists of a motor and a dynamo coupled together. The design of the motor is adapted to the conditions to be met, viz. the power needed, the character of the supply (alternating or continuous current) and the pressure of the supply.

There is also the case of very small offices in which there is no available power supply, and in which it is not economical to provide a special power plant. In such a case the cells are charged from primary batteries, but as a rule the system would only be adopted where single current systems (*i. e.* S.N., D.P.S., and direct and single sounders) are employed.

Where a special dynamo is provided or where a motor generator is employed, the insertion of resistance between the machine and the cells is extremely wasteful in energy, and therefore the current is regulated by varying the E.M.F. of the dynamo or generator. This is accomplished

by means of the rheostat connected in series with the field magnets of the dynamo. The introduction of resistance reduces the flux through the armature and consequently reduces the E.M.F. generated. In this way the excitation

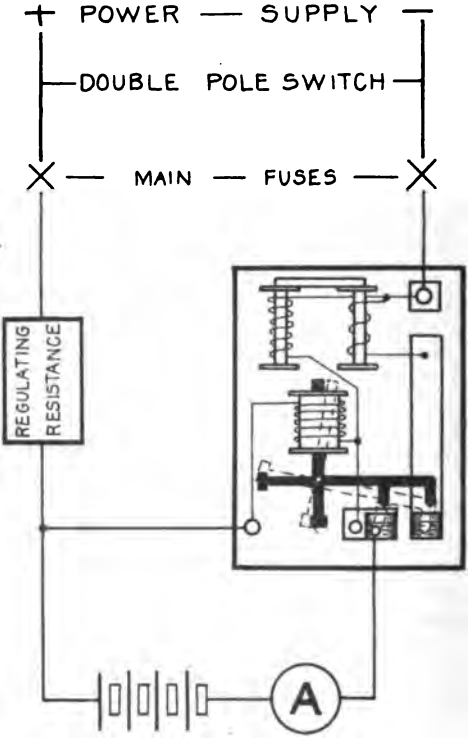


FIG. 272.—Automatic cut out.

may be varied within fairly wide limits without seriously affecting the efficiency of the machine.

The efficiency of a motor generator of small size is usually of the order of 70%, and it is therefore preferable to place resistance in series with the cells when the E.M.F. available is 100v. For this purpose a regulating switch with 20 points and having a total resistance of 22Ω is

provided (*vide* Fig. 272). Where the voltage is 200^{v} or over a motor-generator is more economical.

Where the supply is alternate current there is, of course, no alternative to the use of a motor-generator.

Electromagnetic Cut-outs.

If, from any cause, the dynamo were to stop, the cells would immediately commence to discharge themselves through the machine and serious damage to both the cells and the machine would probably result. This possibility is obviated by the use of the "electromagnetic cut-out" which is included in the circuit between the cells and the machine. Immediately the current reverses, the cut-out breaks the main circuit. In some forms the instrument also operates when the current rises above a certain value determined by adjustment.

The type formerly employed by the Post Office, consists of a special form of polarized relay, with an electromagnet operating a detent, included in its local circuit. The positive main lead from the dynamo passes through the main coil of the instrument and thence through two springs which, during charging, are connected together by the wedge-shaped block of brass fixed upon the movable handle which is carried upon a strong spring. In this position the handle is held by the detent. Under normal conditions the charging current passes through the main coil in such a direction as to leave the polarized relay unaffected. When, from any cause, the current reverses the polarized relay closes the local circuit through the detent electromagnet and the handle flies away, thus breaking the circuit.

The cut-out now used, illustrated in Fig. 272, consists of an electromagnet with a movable polarized armature, mechanically attached to which is a ∩-shaped conductor normally resting above a pair of mercury cups connected in the main circuit. The armature lies within, and is polarized by the 2000$^{\omega}$ coil placed directly across the leads from the cells. The 700$^{\omega}$ winding upon the left limb of the electromagnet is energized by the dynamo acting through the 2000$^{\omega}$ coil. The top of the armature is repelled to the right, but the windings have been so designed and the

weights so adjusted that the E.M.F. of the dynamo must exceed that of the cells by 5 volts before the main connection is made by the descent of the ∩-conductor into the mercury cups. When this happens the main or charging current flows through the '1' coil, and tends to hold the armature to the right. Immediately the current fails or reverses, this coil, which produces a powerful field, repels the armature and breaks the circuit.

It will therefore be seen that the device automatically cuts in the dynamo when its E.M.F. exceeds that of the cells by 5 volts, and that it breaks the circuit instantly the current reverses, due to the cells discharging back through the dynamo.

Other Apparatus Required.

In every case an ammeter is, of course, included in the main circuit for the observation and regulation of the charging current. Where a dynamo or a motor-generator is used a voltmeter is also added.

Size of Cells.

The capacity (A) of the main cells is given by the following formula determined experimentally—

$$A = \frac{4\,C\,(t_1 + t_2)}{N}$$

where C = the sum of the line currents required for every circuit requiring *over* 24^{v} if worked simultaneously.

t_1 = the sum of the times (in hours) during which each double current and quadruplex circuit is worked during the busiest period of the year.

t_2 = one quarter of the sum of the times (in hours) during which all other circuits are working.

N = total number of circuits of all types requiring E.M.F.s of over 24^{v}.

Where the number of single current circuits upon either side of the battery is unequal, provision is, of course, made on the basis of that requiring the larger current.

The capacity (A_1) of the 24^v cells is : —

$$A_1 = \frac{3\,C_1\,t_3}{N_1}$$

where C_1 = the sum of the currents flowing if every line and local circuit upon the more heavily worked side of the 24^v battery is in operation.

t_3 = one quarter of the sum of the time in hours during which each circuit is used during the busiest period of the year.

N_1 = number of circuits operated from the more heavily worked side of the battery.

These formulæ provide a margin of 60%.

CHAPTER XVI

ALTERATIONS IN THE CIRCUIT CONNECTIONS FOR UNIVERSAL BATTERY WORKING.

THE general principles underlying the changes which are made in the connections of the apparatus for universal battery working are of a simple and obvious character. In the previous chapter it was pointed out that the sending circuits must be simplified to the general form illustrated in Fig. 253. Where currents in both directions are to be transmitted, the two keys or the two positions of the one key must connect either the positive or the negative earthed battery to the line. Excluding the case of intermediate offices, it will be seen that, having altered the sending portion of the key or keys to fit the new conditions, the same terminal of the set must be connected through to line in every case whether the station is up or down. For a down station this entails the reversal of the battery and the reversal of the direction in which the relay is connected. It will also be obvious that the key or keys must not connect the battery to earth.

In the case of intermediate offices the key or keys must be of the same type as in ordinary working, since it is necessary to connect the negative E.M.F. to the up line, whilst the positive E.M.F. is joined to the down line, or *vice versa*. Since the key or keys merely effect a reversal, the same E.M.F. is necessarily connected to both the up and to the down line. Where the resistances of these lines differ widely artificial resistance is introduced into the shorter line in order to prevent the current sent out attaining too high a value.

These are, then, briefly the general underlying principles which govern the changes necessary, and a careful review

of the above generalizations should, after reading the details of the various changes, prove of service in memorizing the general scheme.

SINGLE CURRENT WORKING.

Single Needle.

The alterations required upon single needle circuits may best be demonstrated by considering the effects which result when a universal battery is joined to *Z* and *C* of the commutator of an up station. The received signals are not affected by this substitution. If the right key is depressed the negative voltage is connected to line through the dial, but the positive voltage is connected to earth at the up line terminal. The depression of the left key joins the positive voltage to line, but earths the negative. The currents sent out to line are in each case in the direction to produce the correct signals at the down station. Now the alterations to the commutator are such as to prevent the voltage which is not connected to line from being earthed. This is effected by cutting away or bending the right-hand portion of the "copper" spring so that it is out of reach of the lever when the key is depressed, and by either removing or disconnecting the front contact screw of the left key. The latter course is preferable, since it does not affect the play of the key. It may readily be done by removing the copper spiral which serves to connect the contact screw to the wire running to *Y* beneath the base of the commutator. The alterations are clearly indicated at S_1 and S_2 in Fig. 273.

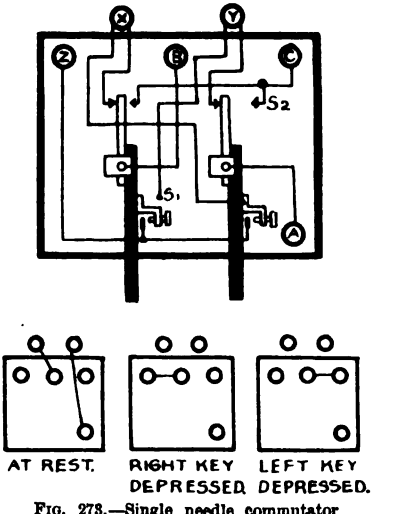


FIG. 273.—Single needle commutator modified for universal battery working.

In order to work to an up station the dial and the direction in which the voltages are connected to Z and C is reversed. These changes are necessary since the currents are sent out from the down line terminal of the key, which must therefore be connected to the line. The reversal of the battery makes the signals straight at the up office, whilst the reversal of the dial straightens the signals sent out and those received upon it.

An intermediate office requires a commutator with all its connections precisely as in ordinary working. When the

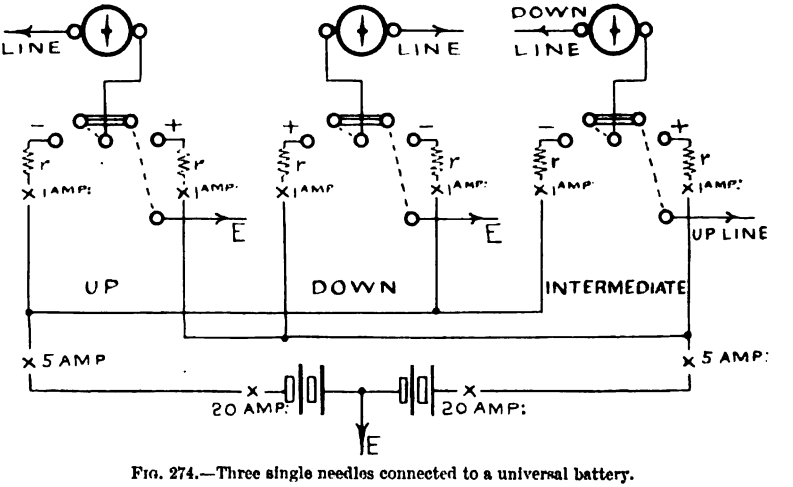


FIG. 274.—Three single needles connected to a universal battery.

right-hand key is depressed the positive and negative voltages are respectively connected to the up and down lines. The current through the up line is produced by the positive, whilst that through the down line is due to the negative, battery. Depression of the left key reverses this condition, and therefore the same value of E.M.F., but in the reverse direction, is necessarily connected to the up and down lines. The dial (200$^{\omega}$) is included in the down line. If the resistance of the up line circuit is 1200$^{\omega}$ and the down line 600$^{\omega}$ (including the dial), the currents sent out are respectively 20 m.a. and 40 m.a. with 24^{v}. This disparity may be rectified by putting a 600$^{\omega}$ resistance coil in the down line.

It is, however, far better to avoid cases of this description, since it entails increasing the battery power at each office in circuit.

The connections of an up, a down, and an intermediate office, connected to a universal battery, are depicted in Fig. 274. The fuses, etc., which intervene between the cells and the keys have been suitably indicated.

Summary of Alterations to Single Needle Circuits.

Up and Down Offices.

1. Commutator (*a*). Disconnect left front contact screw.
„ (*b*) Raise back right-hand battery spring.

Up Offices.—Remaining connections unaltered.

Down Offices.—1. Reverse the connections on the dial.
2. Join + to *Z* and − to *C*.
3. Connect the dial to line and *A* to earth.

Intermediate Offices.

All connections unaltered.

Resistance should be inserted in the line of lower resistance if the up and down sides differ greatly; the dial (200ω) is in the down line circuit.

Use of Resistances between the Fuses and Instruments.

Owing to the very general use of heat coils it has been found necessary to provide against the coils being operated by the increased current sent out through a line fault. Moreover, the number of fuses blown by momentary short circuits at the instruments was considerable. Accordingly, metal-cased resistance coils (marked "*r*" in Fig. 274), are introduced between the 1-ampere fuses and the instruments upon all circuits requiring less than 80ᵛ. Where 80ᵛ or over is in use an ordinary 100ᵛ 16 candle-power incandescent lamp is similarly interpolated. In every case the resistance inserted amounts to about 2ω per volt of E.M.F. in use, thus ½ ampere is the maximum current which can be produced through a dead short circuit.

The values of the metal-cased resistance coils are as follows :—For 24ᵛ—50ω, for 40ᵛ—80ω, and for 60ᵛ (older installations) 120ω. The resistance of the lamps is about 300ω.

Double Plate Sounders.

Double plate sounder circuits are dealt with in similar fashion to single needles, and consequently the commutator must be altered for up and down sets but not for intermediate working.

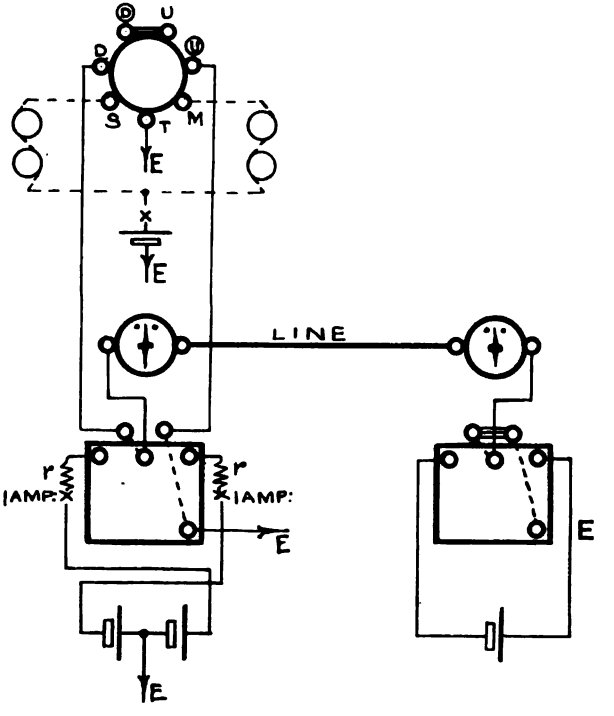


Fig. 275.—Double-plate sounder down office working to single needle. The up terminal of the commutator at the single needle end should be connected to earth.

The two ends of a circuit, of which the universal worked station is the down office, are shown in Fig. 275. It will be observed that the positive and negative voltages are respectively connected to *Z* and *C* whilst the relay and single current galvanometer are reversed. By tracing the path of the current in every position of each commutator, it will be found that the effect of the changes is to cause the

currents to be correctly received at the up station and at the same time to deflect the single current galvanometer in the right direction, whilst the reversal of the relay has straightened the received signals at the down station.

The metal-cased resistances and fuses are precisely as in the single needle. The tongue of the relay is connected to a common earth running along the tables, and the 24^{v} battery is connected through a 1-ampere fuse to the junction of the two sounder coils (each 900$^{\omega}$), as indicated in Fig. 275. Resistance coils are not, of course, inserted in the local circuit, since the reasons which lead to their introduction in the line battery leads do not apply in this case.

Summary of Alterations to Double Plate Sounder.

Up and Down Offices.

1. Commutator. As in single needle.

Up Office.—Remaining connections unaltered.

Down Office.—1. Reverse the galvanometer.
2. Join + to *Z* and − to *C*.
3. Connect the galvanometer to line and *A* to earth.
4. Reverse the relay by connecting *X* to *D* and *Y* to *D*-circle.

Intermediate Offices.

All connections unaltered.

Resistance should be inserted in the line of lower resistance if the up and down sides differ greatly; the galvanometer (30$^{\omega}$) is in the down line circuit.

Single Current Sounders.

After the consideration of the single needle and double plate sounder circuits, the single current sounder alterations are, with the exception of intermediate stations, of a fairly obvious character. An up and a down set are shown in Fig. 276, from which it will be seen that the galvanometer is reversed and the negative voltage connected to the key in the case of the down station.

An intermediate station is shown in Fig. 277. The six-terminal reversing key is substituted for the single current

key, and both positive and negative voltages are required. With this key at rest, a positive current coming in on the up line passes through the relay in the direction *U* to *D* and out on to the down line. When the key is depressed the negative voltage is joined to the down and the positive to the up line, and the currents are therefore in the correct direction to actuate the relays at the terminal stations. A second galvanometer is employed in order to indicate currents going out upon both sides. Where the resistances

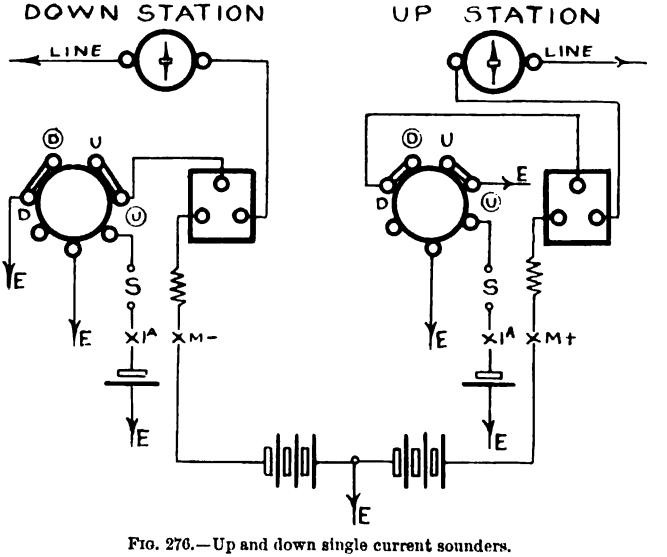


FIG. 276.—Up and down single current sounders.

of the up and down sides differ considerably, a suitable resistance may be introduced between the metal-cased resistance and the key upon the side having the lower resistance.

Direct sounders and direct writers are dealt with upon the same principle in each case, but it should be pointed out that 900$^{\omega}$ sounders are used at the out station, while "D" relays are employed to receive the out station's signals. This is, however, merely a question of economy of battery power, and should not require further comment.

Single Current Duplex.

In Chapter VII it was pointed out that the battery resistance coil shunts the plain coil of the relay during simplex working. In order to avoid this, a 9-terminal 2-position switch has been introduced. In duplex working the centre of the key is connected to the split of the relay and the coils of the galvanometer are joined in series with the coils of the relay as in quadruplex working. In the simplex position of the switch the battery coil is disconnected, and

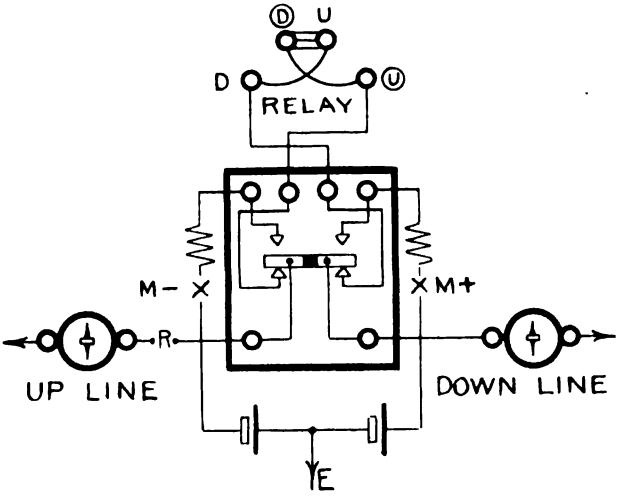


Fig. 277.—Single current sounder intermediate station.

the connections are precisely as in ordinary simplex sets, save that the right-hand coil of the galvanometer is substituted for the single current galvanometer employed upon such circuits. This will, however, be quite apparent from a consideration of Fig. 278. If the set is required to work as a down station the negative voltage is joined to the key and the *D* and *U*-circle connections of the relay reversed. These points will, however, be apparent after the detailed consideration accorded to the more extensively used double current duplex.

There is a small number of circuits having lines which

are entirely underground, where the duplex switch is omitted and the circuits permanently duplexed. The connections are, however, identical with those of the set shown in Fig. 278 when at duplex, but with the switch connections directly made.

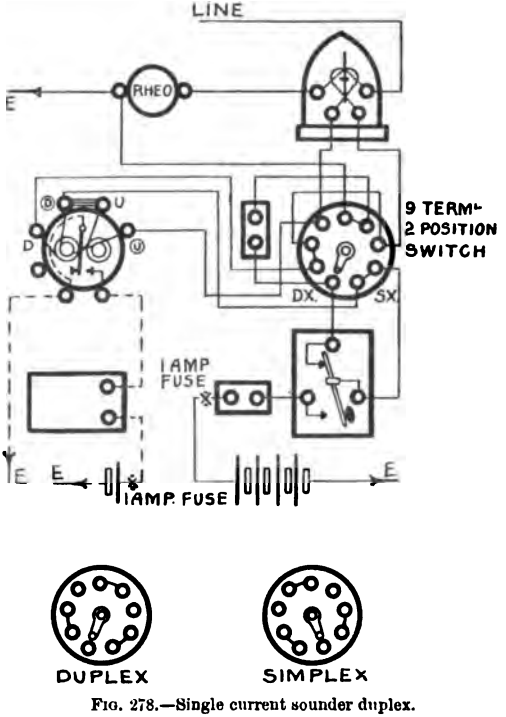


FIG. 278.—Single current sounder duplex.

DOUBLE CURRENT SOUNDER.

Double current working may, in the case of an up station, be effected by disconnecting the front left-hand terminal of the key and joining the positive and negative voltages to *Z* and *C*. For a down station, the galvanometer, relay, and battery connections would have to be reversed, the line joined to the galvanometer and the relay earthed,

still leaving the left terminal of the key disconnected. These statements may, with advantage, be compared with the reasons given for the alterations to the commutator and for those made to a double plate sounder down station.

As double current circuits are very numerous, a special key of simple form has been designed. It is known as the "single current key with switch" (Fig. 279), and consists of a single current key with a two-way switch mounted upon the one base. The front right-hand terminal is connected to the centre of the switch and corresponds to the similar terminal of the ordinary double current key. At receive, the two front terminals are joined across, and therefore the left corresponds to the central terminal of a double current key. *Z* and *C* are, as in every form of key, respectively upon the left and right, whilst *C* is connected to the front stop of the key. The skeleton connections in each position of the key are shown in Fig. 280.

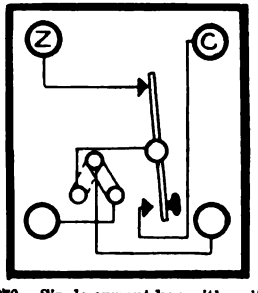


FIG. 279.—Single current key with switch.

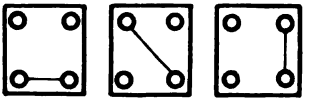


FIG. 280.—Skeleton connections in each position of single current key.

Two circuits, the one an up, and the other a down station, are shown connected to a universal battery in Fig. 281. The up set calls for little comment since the connections are as in ordinary double current working, save for the substitution of the four-terminal key. In the case of the down set the connections of the relay are reversed, as also are those of the galvanometer. The positive and negative voltages are connected to *Z* and *C* respectively whilst the line is joined to the galvanometer. By sketching the arrangement working to an up office it may readily be shown that the alterations straighten the signals at either end, and that the reversal of the galvanometer makes the directions of the deflections the same as for an up set.

For intermediate sets the ordinary double current key is

retained, since currents have to be sent out upon both the up and the down line. Where the up and down lines differ greatly in resistance, a suitable resistance coil is inserted between the relay and the left side of the key, as shown in Fig. 282. In this way the resistance of the up is made equal to that of the down line. Where the conditions are reversed, *i. e.* where the down line has the lower resistance, the battery and the relay are each reversed, as also are the positions of the up and down lines.

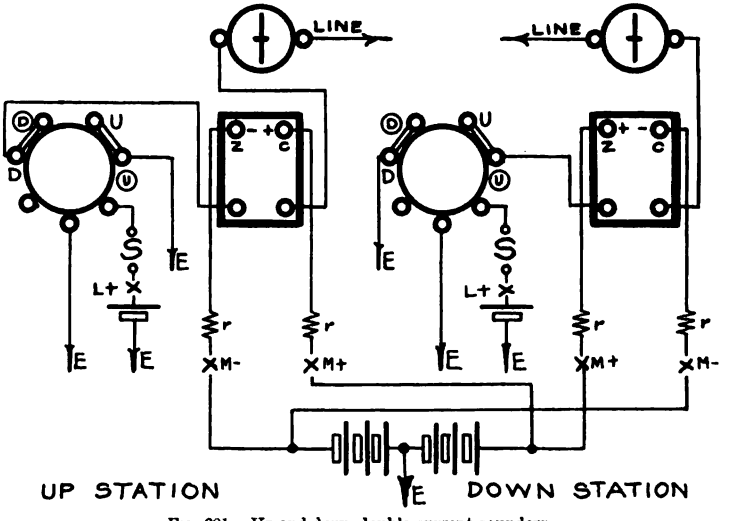


FIG. 281.—Up and down double current sounders.

The balancing resistance is not included in the path of the currents received from the terminal stations, and their battery powers are not, therefore, increased, as in the case of single needle circuits when changing from separate to universal battery working. By the aid of Fig. 282, which shows the terminal, as well as the intermediate, stations, the conditions stated may readily be verified.

DOUBLE CURRENT DUPLEX.

The arrangements necessary for duplex working, although somewhat different from those previously considered (see

Fig. 117), are by no means complex. A single current key with switch takes the place of the ordinary double current key and the separate coils of the galvanometer are placed in series with those of the relay, since the "double split" cannot be employed. The skeleton connections of a duplex station working to a down station of the ordinary type are shown in Fig. 283.

In the normal position, with both keys at rest, the path of the current is from the positive pole of the universal battery to earth, in at the down station galvanometer, through the battery, through the line coil of the relay (*D*-circle to *U*-circle) to line, through the right-hand coil of the home galvanometer, through the relay (*D*-circle to *U*-circle) back to the battery. The current

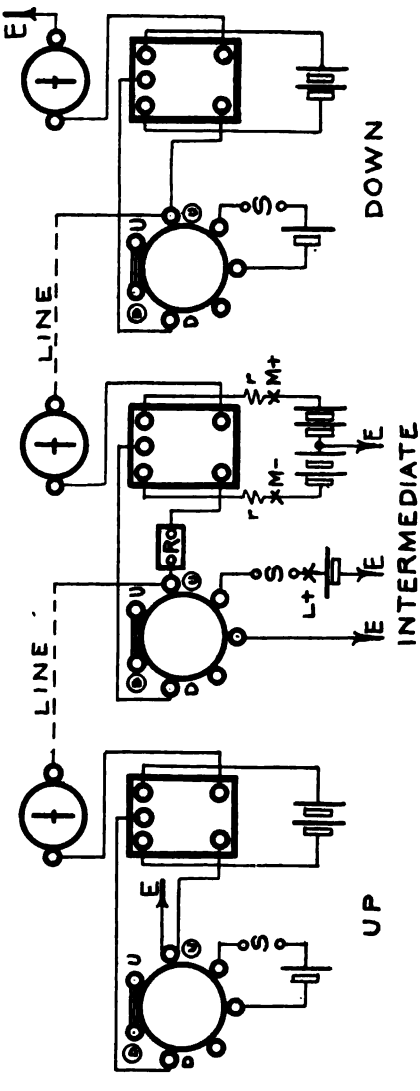


FIG. 282.—Double current sounder intermediate station.

in this circuit is twice as great as that in each of the compensation circuits, and the preponderating current therefore produces a space at both ends. If both keys are down the current is throughout reversed in direction, and a mark is therefore registered at each end. When one key only is depressed the batteries oppose, and the compensation circuits

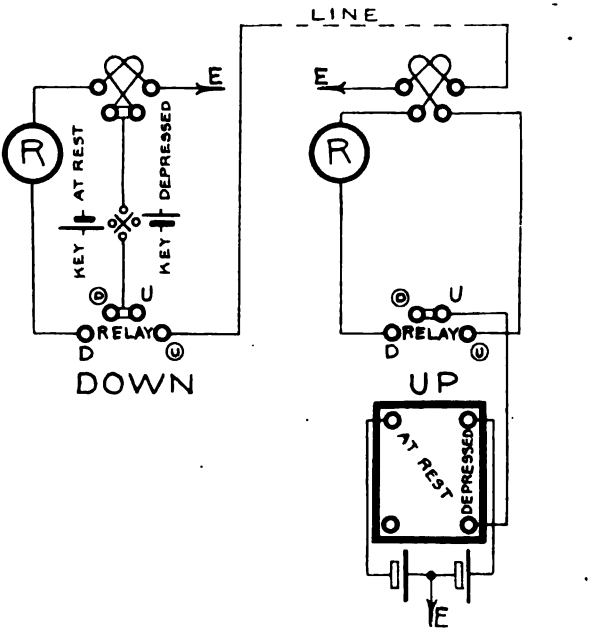


FIG. 288.—Principle of double current duplex working with universal battery.

are left free to produce a space at the end where the key is down, and a mark at the station where it is at rest.

The single current key produces a disconnection when moving from the normal to the depressed position, or *vice versa*. The condition is of momentary duration only, and no evil effects result. The point was, however, fully considered in relation to ordinary duplex current working (*vide* page 234), and no further comment should be necessary.

The connections of an up station are shown in Fig. 284. The skeleton duplex connections have already been dealt with (Fig. 283), and it therefore remains to indicate how they are altered for simplex working. When the switch is turned to the simplex position, the split wire is disconnected, the left-hand terminal of the key is connected to *D* of the relay, and the line connected through the right-hand coil of the galvanometer to the front right-hand terminal of the key. The path of a received current is

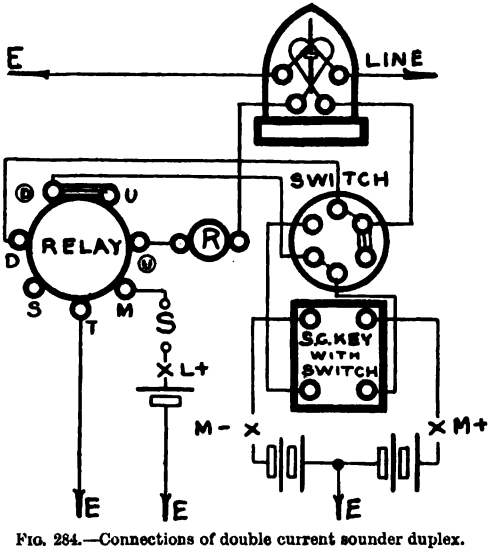


FIG. 284.—Connections of double current sounder duplex.

through the line coil of the galvanometer, *viâ* the strapped terminals of the duplex switch, through the key, relay, rheostat and left coil of the galvanometer. Since the rheostat is in circuit at simplex, care should be taken to see that no resistance is left in it. The currents sent out pass to line through the right-hand coil of the galvanometer only.

For simplicity, a rheostat only has been shown (Fig. 284) in the compensation circuit, but where the line is of sufficient length, a condenser, condenser coils, and retardation coils are, of course, added as in ordinary duplex working.

The figure shows the connections for an up station. At a down station D and U-circle are reversed, and positive and negative voltages are respectively connected to Z and C.

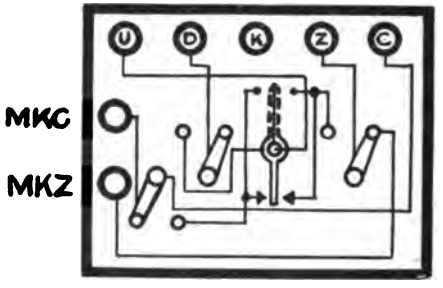


FIG. 285.—Wheatstone transmitter with upper contacts removed.

WHEATSTONE.

It is essential that the transmitter shall not connect either voltage direct to earth, and accordingly the two upper

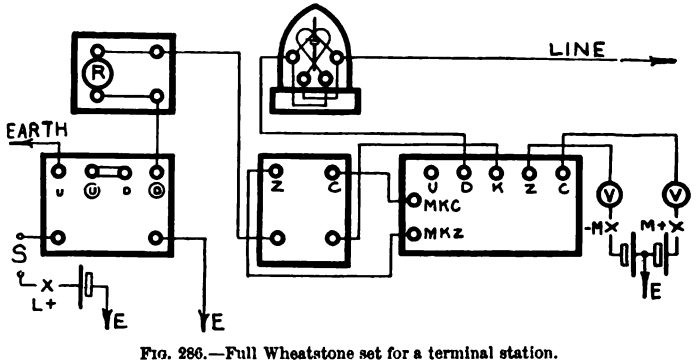


FIG. 286.—Full Wheatstone set for a terminal station.

contact points are withdrawn from the reach of the divided lever, as indicated in Fig. 285.

The connections of a full Wheatstone circuit are shown in Fig. 286, and call for but little comment. With the transmitter running, currents are sent to line from D. At rest, the positive and negative voltages are joined to Z and

C of the key, and its currents pass to line through *K* and *D*. The *U* terminal of the transmitter is unconnected. The remaining portions of the circuit are apparent.

For a down station the connections of *D*-circle and *U*

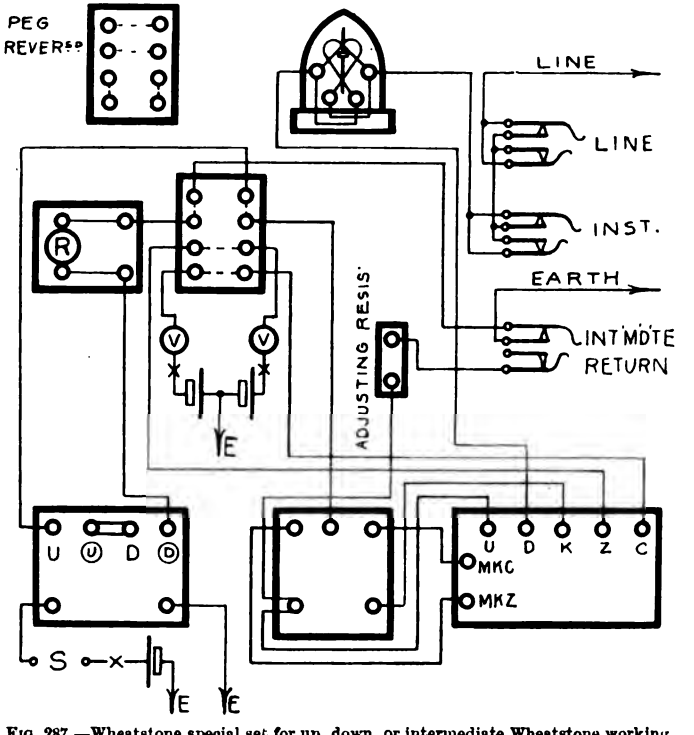


FIG. 287.—Wheatstone special set for up, down, or intermediate Wheatstone working. (Peg switch connections for working as a down station to the long lines.)

and those of the galvanometer are reversed, whilst the battery is reversed at *Z* and *C* of the transmitter.

A lamp is inserted in each battery lead for the reasons given upon pages 319 and 489.

SPECIAL CIRCUITS.

In every large office there is a number of Wheatstone sets which are used only for "special" work, such as race

meetings, speeches, and cricket matches; also a number of circuits which only require to work Wheatstone occasionally, or which need it during certain hours of the day, are fitted so that they may be used for special work. All these circuits are fitted with transmitters and receivers, and provision is also made for intermediate working if required. As the sets may be required to work as up or down, and as the shorter line in intermediate working may be either an up or a down line, a reversing switch is added, so that the requisite changes may be made at the instrument. The difference between the resistances of the up and down sides in intermediate working, of course, varies with the lines connected, and therefore the balancing resistance is adjustable—it is, in fact, a set of condenser coils (Fig. 39).

The connections of a special set are shown in Fig. 287. The test-box arrangements are described in Chapter XVIII, and it will, therefore, only be necessary to remark that the line passes through the line and instrument switch springs to the galvanometer, and that the "intermediate return" switch spring is used for the connection of the second line when working intermediate. This line is always the shorter, or line of lower resistance.

The reversing switch is of the "peg" form, and consists of eight springs corresponding to the eight terminals. The peg also carries eight springs, four upon either side of the ebonite handle which supports them. These springs are connected together, as indicated by the dotted lines in Fig. 287, and therefore reversing the peg connects the four top terminals horizontally and the lower four vertically. The four upper terminals control the reversal of the receiver, and the lower set the reversal of the battery.

When used as a terminal station there is no line connected to the intermediate return switch spring, and consequently *U* of the transmitter and the left terminal of the double current key are disconnected. The arrangement is then identical with that of Fig. 286, save that the double current key does duty for the single current key with switch. The reversing switch is used to alter the set to up or down as may be required when any new circuit is connected to it.

When the set is required for intermediate working the shorter line is connected to the "intermediate return"

switch spring by means of solid plugs and cords. The insertion of the plug cuts away the earth connection, and bunches the wires from the adjusting resistance and the receiver (*viâ* the switch) to the short line. Suitable resistance is then inserted in the adjusting resistance box and the signals straightened, if reversed, by reversing the peg switch. In the latest arrangement a second galvanometer

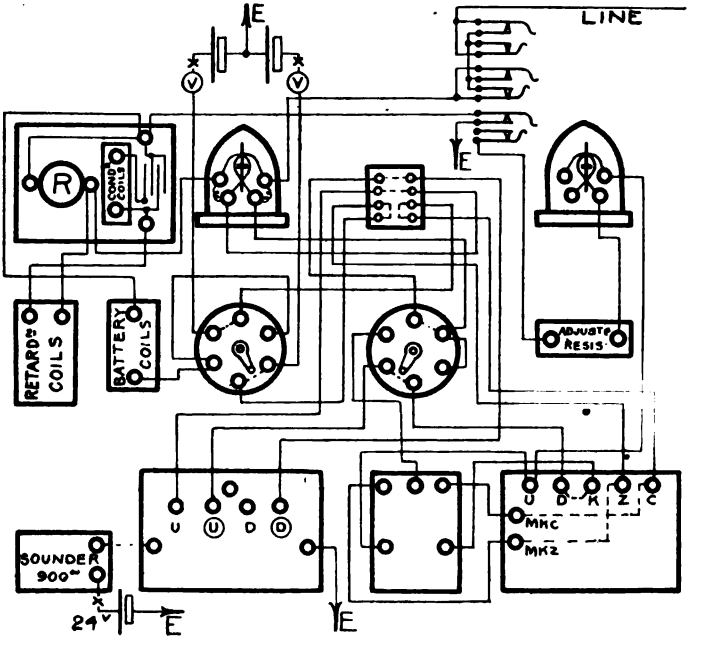


FIG. 288.—Wheatstone special set for duplex or simplex terminal or intermediate working. (Peg switch connections for working as an up station to the long line.)

is placed in series with the adjusting resistance (compare Fig. 288).

The received currents pass from the long line, through the galvanometer, through *D* and *K*, through the receiver and shunted condenser out on to the short line. The adjusting resistance does not form part of the received circuit. Transmitter currents pass out between *U* and *D* of the transmitter, and the adjusting resistance is included

in the circuit of the shorter line. The key currents pass through D and K of the transmitter and the adjusting resistance.

Wheatstone Duplex for Special Sets.

The connections of a special set arranged for duplex, simplex, terminal, and intermediate working are shown in Fig. 288. The battery switch normally connects the posi-

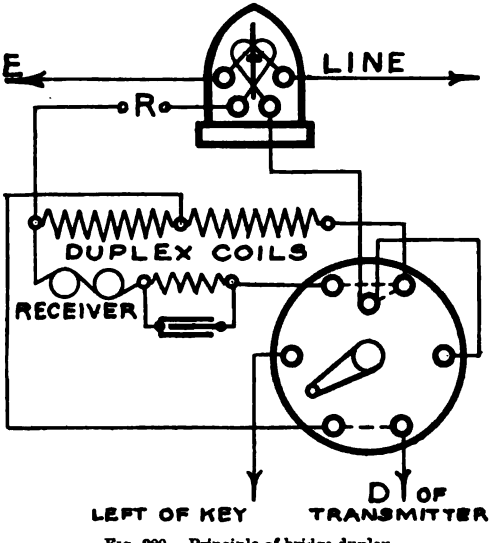


Fig. 289.—Principle of bridge duplex.

tive and negative voltages to the peg switch, which is arranged as in simplex working, *i. e.* it serves to reverse the battery and to reverse the relay terminals. The battery switch in the "resistance" position joins both Z and C of the transmitter through the battery coils, one side of which is permanently earth-connected. The duplex switch is arranged as in Fig. 284, and by comparing it with Fig. 288 there should be no difficulty in tracing the arrangement through. It will also be observed that a second galvanometer is added for intermediate working.

Wheatstone Duplex (Differential System).

In this case the transmitter is added precisely as in Fig. 286, and *D* of the transmitter is joined to the lower terminal of the duplex switch. The receiver takes the place of the relay shown in Fig. 284, and the battery switch is arranged as in the "special set" duplex (Fig. 288). A reversing switch is not provided, and the single current key with switch is, of course, used in place of the double current key, and the upper contacts of the divided lever in the transmitter are withdrawn. The working out of the actual connections should now prove quite simple, and this is left as an exercise for the reader. The full connections are, of course, given in the official diagram book.

Wheatstone Duplex (Bridge System).

The changes necessary for the bridge duplex are of a fairly obvious character. One coil of the galvanometer is placed in series with the right-hand duplex resistance coil, whilst the second coil is added to the compensation circuit. The positive and negative voltages are joined to a 6-terminal 2-position switch just as in the special duplex, whilst the single current key with switch and the transmitter are connected as in Fig. 286. The connections of the duplex switch are indicated in Fig. 288, and no difficulty will be experienced in elaborating the connections.

QUADRUPLEX.

The only feature which is really special to the universal battery worked quadruplex is the arrangement of the sending circuit. The other additions, viz. the quadruplex and simplex switch, the bridging coil in the compensation circuit and the switch for measuring the line currents, might, with equal advantage, be applied to circuits worked by separate batteries.

The principle of the sending circuit may be stated in a few words. The key upon the *B* side joins both the positive and the negative voltages through to the *A* key. The *B* key determines the value of the E.M.F., whilst the

A key selects either the positive or the negative voltage according to its position.

The *B* key (known as the "6-terminal reversing" key) (Fig. 290) is of the double current form, but is without a switch, whilst the four contact springs are connected to four upper terminals. The *A* key is an ordinary double current key. In this, as in every other case, the battery leads pass through fuses and resistances on their way to the key. The lower voltage leads required metal-cased resistance coils, whilst the higher voltage leads are provided with lamps. These resistances are all approximately

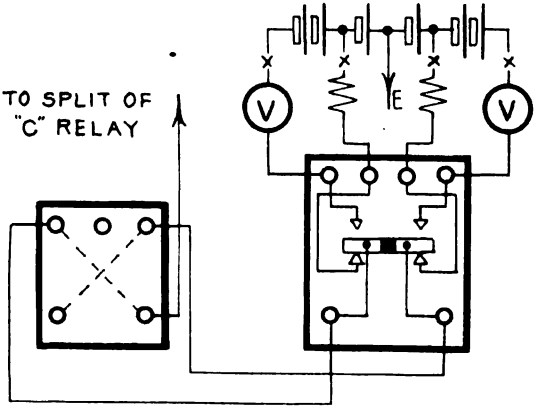


FIG. 290.—Connections of keys in quadruplex.

300ω, hence the resistance of the battery circuit is the same in both positions of the key. The double current key must be of the latest form with adjustable contacts, and should short circuit in the intermediate position.

The *B* key at rest connects the lower voltages to *Z* and *C* of the double current key. When depressed the higher voltages are so connected. The double current key connects either the positive or negative side of the battery to the wire going to the strapped terminals of the non-polarized relay. Since the paths and directions of the currents are necessarily the same as in the quadruplex previously described it is not necessary to trace them.

It has been pointed out that the self-inductance of the distant apparatus is, in the case of a short duplex circuit, sufficient to prevent a balance being obtained. The same remark applies to quadruplex working, and therefore a bridging coil, having a self-inductance equal to that of one coil of each relay and one coil of the galvanometer,

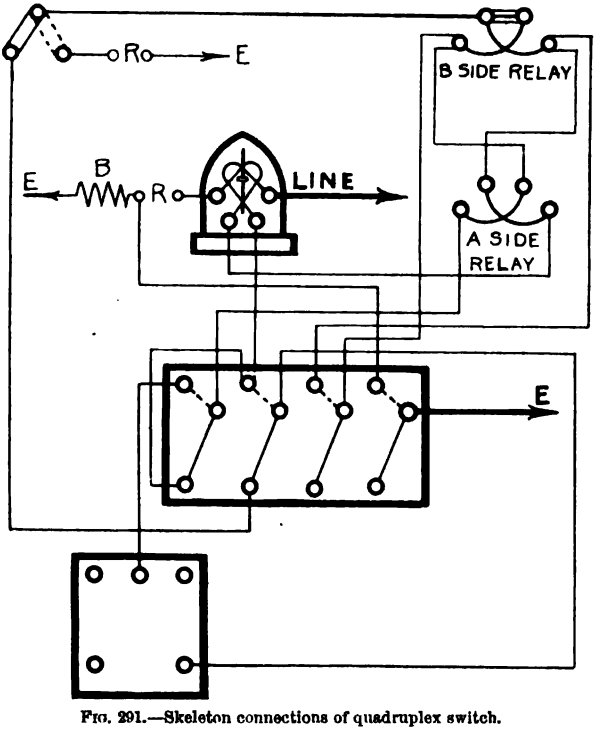


FIG. 291.—Skeleton connections of quadruplex switch.

is added to the compensation circuit. It is, however, only required upon very short circuits. The bridging coil, so called on account of the use to which it is put in telephone circuits, consists of a coil of wire wound upon a soft iron core, over which an iron tube is placed, and the ends closed by iron discs in such a manner as to form a closed magnetic circuit.

The full connections of a universal battery worked quadruplex set are shown in Fig. 292. With the switch at quadruplex the connections are as in Fig. 118, save that the keys are arranged as in Fig. 290. When the switch is turned to simplex the *D* and *U*-circle coils of the *C* relay are short circuited, which is equivalent to connecting *D*-circle

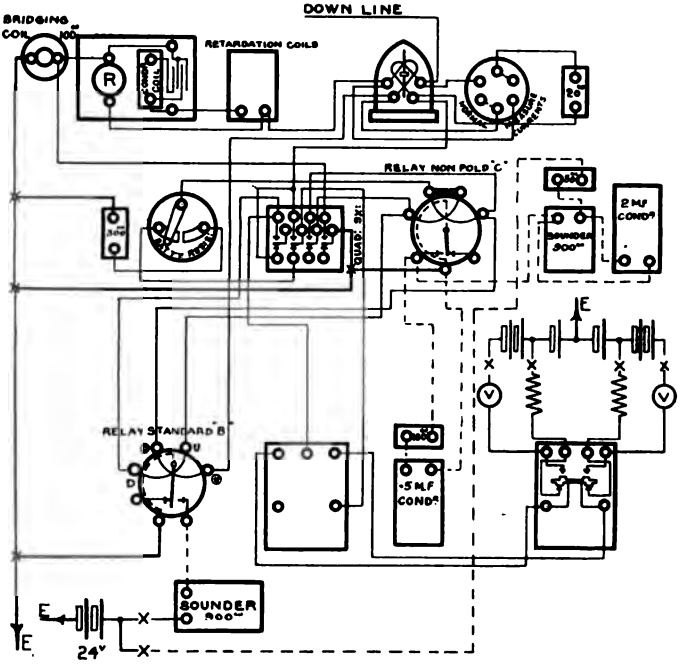


Fig. 292.—Connections of a quadruplex.

and *U* of the *A* side relay. The *D* terminal of the *A* side relay is connected to the centre, and the lower right-hand terminal of the galvanometer is joined to the right, of the double current key. The path of a received current is then, through the right-hand coil of the galvanometer through the key (switch to receive), through the *A* side relay, left coil of the galvanometer, and through the rheostat to earth. It will be observed that right side of the bridging coil is earthed when the switch is at simplex.

The path of the sent current is through the right-hand coil of the galvanometer direct to line.

The 6-terminal switch placed near the galvanometer short circuits the left coil and shunts the right coil by 20ω, when turned to the "measure currents" position. The degrees of the galvanometer correspond roughly with the current in milliamperes flowing through it. By turning the battery switch to the right the current received may be measured, whilst the current sent out may be obtained by requesting the distant office to earth.

If the apparatus is required to work as a down station the wires on *D* and *U*-circle of the *A* side relay, those upon the upper and those upon the lower terminals of the galvanometer, and the battery wires on the *A* key should each be reversed.

The full connections of an increment quadruplex with Wheatstone upon the *A* side are shown in Fig. 293. The most notable feature is the method by which the power is increased whilst the transmitter is in operation. The resistance of the contacts made by the divided lever are far higher than those of the double current key, with the result that the currents sent out when the *B* side key is depressed are seriously reduced in value. In order to correct this defect the *U* terminal of the transmitter is joined to an earth-connected neutral relay. The local contacts *S* and *M* are both connected to an auto switch (*vide* p. 520), whilst *T* and the other side of the switch are earthed. When the transmitter is running currents are sent out from *U* of the transmitter through the 3000ω resistance coil and the neutral relay. These currents hold up the armatures, which, in this position, increase the voltage connected to the two outer terminals of the *B* side key. So long as the transmitter is running the automatic switch is closed.

When the switch is turned from quadruplex to duplex the connections of a Wheatstone duplex are produced, but this and the other details of the arrangement will be quite apparent from the figure.

At a down office the wires on *U* and *D*-circle of the receiver, the wires on the upper and on the lower terminals of the galvanometer, and the wires on the front terminals of the "*B*" key are each reversed.

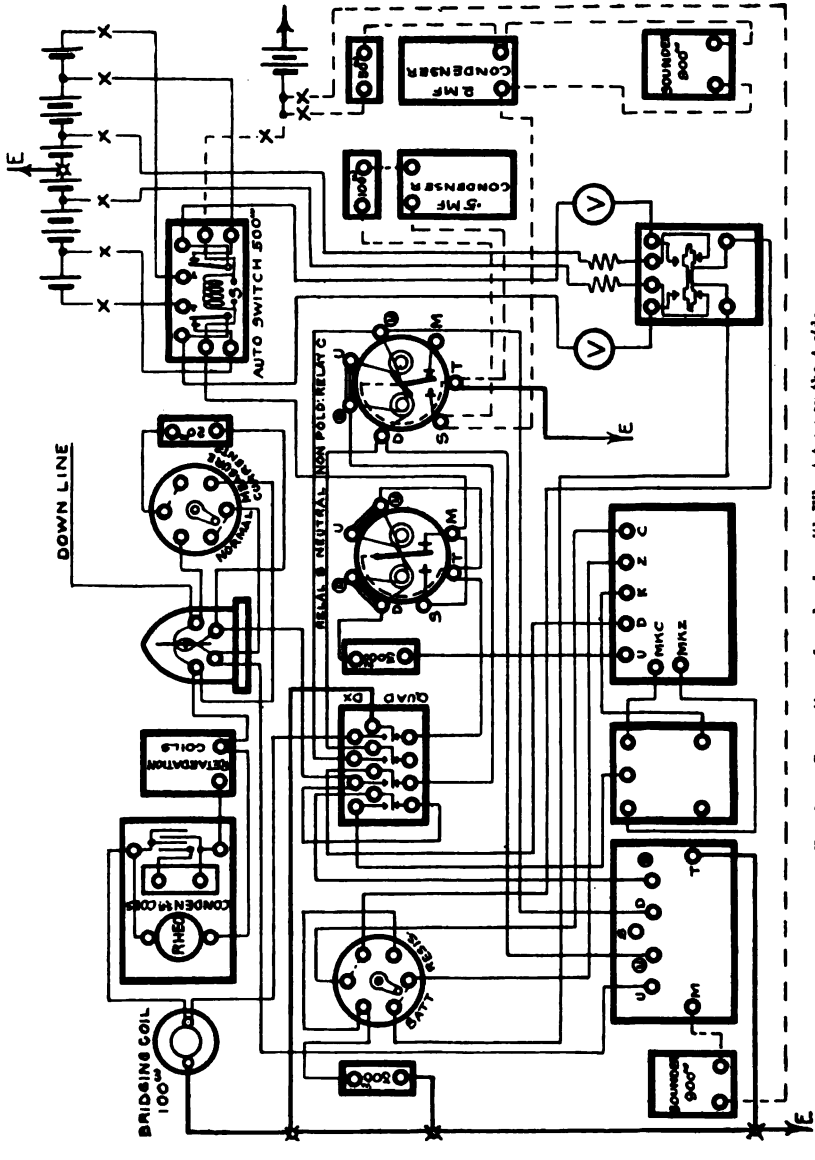


Fig. 298.- Connections of quadruplex with Wheatstone on the A side.

Test Box Speaking Set.

The only feature of the arrangement which is not common to an ordinary double current set with facilities for intermediate working is that any of the voltages from 24^{v} to 120^{v} may be connected to it according to the positions of the two **U**-links (Fig. 294).

Universal Working with Primary Batteries.

As indicated in the last chapter the circuits connected to

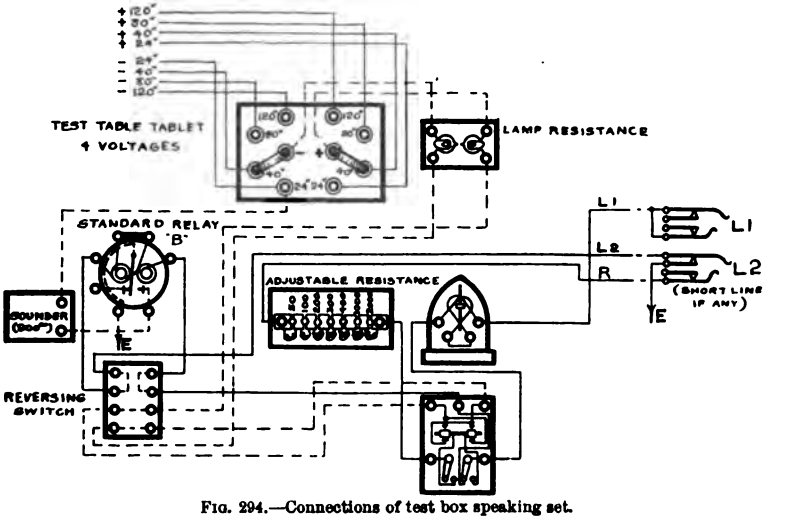


Fig. 294.—Connections of test box speaking set.

a primary universal battery should not exceed five or six at most, and their resistances should not differ by more than 25%. Where this is the case resistances are inserted in the battery leads to the instruments, *i.e.* in the position in which the fuses are placed in secondary cell working. With this exception the circuits are arranged as indicated in each case. Single needles, double plate sounders, sounders simplex, and short duplex may be successfully worked from a universal primary battery consisting of bichromate cells, but long duplex, quadruplex, Wheatstones, and repeaters should invariably be given separate batteries when secondary cell working is not in vogue.

CHAPTER XVII

REPEATERS.

Working Speed of a Circuit.

THE time taken for the current in any given circuit to rise to any specified percentage of its maximum value is inversely proportional to the product of the total capacity and total resistance of the line. This value is obviously related to the working speed of the circuit, and, by collecting the results of a very large number of experiments, the following empirical formulæ have been obtained :—

$$W_1 = \frac{10{,}000{,}000}{KR}$$

$$W_2 = \frac{12{,}000{,}000}{KR}$$

$$W_3 = \frac{18{,}000{,}000}{KR}$$

where

W_1 = speed in words per minute obtainable upon an aërial iron wire line.

W_2 = speed in words per minute obtainable upon an aërial copper wire line.

W_3 = speed in words per minute obtainable upon a subterranean or submarine gutta-percha-covered wire.

K = total capacity of the line in micro-farads.

R = total resistance of the line in ohms.

These formulæ assume that a shunted condenser is used at the receiving end, and that the battery power is upon the basis of that required to furnish 8 m.a., with a minimum E.M.F. of 100 volts. It also assumes that the battery resistance does not exceed 3$^{\omega}$ per volt of E.M.F.

The working speed obtainable from the formulæ is, of course, subject to the limit of the speed at which the apparatus can be worked, and this does not exceed 600, and, in practice, is rarely above 400 words per minute.

A rapidly alternating current does not evenly distribute itself throughout the cross section of the conductor through which it is flowing. The current is densest upon the outer parts and is least dense in the centre. Owing to the fact that iron is a magnetic material, this "skin effect" is more marked with iron than with copper conductors. Taking an iron and a copper wire of equal length and equal resistance to a steady current it would be found that the iron wire offered a higher resistance than the copper one to an alternating current. It is to this fact that the lower speed obtainable with an iron wire is to be attributed and not to the fact that the iron wire possesses a higher self-inductance than the copper one. The increased self-inductance would be distinctly beneficial and not detrimental (see p. 514).

Battery Resistance.

The internal resistance of the battery employed upon a Wheatstone circuit has an important effect upon the speed of working. If the resistance is below 1$^{\omega}$ per volt of E.M.F. used, the transmitter will very quickly be placed out of action by excessive sparking whilst a value in excess of 2·5$^{\omega}$ per volt will reduce the working speed. Consideration will show that the action of resistance in the sending circuit will be in every way similar to the action of the retardation and condenser coils used to slow down the rate at which the condensers in the compensation circuit of an ordinary duplex are charged. The *maximum* value of the current in the *sending* circuit of a Wheatstone circuit is frequently well over 250 m.a., whereas the received current may not exceed 10 m.a. It is for this reason that heat coils having a striking-point of 500 m.a. are invariably used

upon such circuits in preference to those having a striking-point of 250 m.a. (see p. 578).

Distributed Leaks and Inductance Coils.

Two solutions of the problem of increasing the working value of telegraph and telephone circuits by alterations to the circuits have been proposed. The first consists in reducing the insulation of the circuit by the application of a large number of "leaks" evenly distributed throughout the circuit. This proposal reduces the value of the received current and experiments upon a small scale seemed to show that the improvement effected was of a somewhat doubtful order. At all events, no administration has had the courage to risk the experiment upon a very long cable. In the case of long open lines and open lines allied with underground sections there is no authentic case in which the working speed has been increased owing to a small or large fall in the general insulation of the circuit. Upon the other hand, it is found that when the total insulation is less than the conductor resistance the speed is materially reduced.

The second proposal is due to Oliver Heaviside and consists in giving to the circuit *distributed self-induction* in just the same way that it already possesses distributed capacity and resistance. The condition is approximately satisfied if the self-induction is provided by inserting coils in the lines at frequent and regular intervals. So far, the device has been applied almost exclusively to telephone circuits, and has resulted in the efficiency of the treated or loaded circuits being raised to from twice to three times the efficiency of the untreated circuits. The resistance, self-inductance, etc., the distance between successive coils varies with the resistance, capacity and length of the circuit to be dealt with, but the values of each coil range from resistance 1^{ω} to 10^{ω}, self-inductance ·04 to ·1 henry, and the distance apart from $\frac{3}{4}$ to $1\frac{1}{2}$ miles. In most cases the coils are without iron cores since their introduction would lead to eddy current losses, but where iron is used it must be in a finely divided condition.

In the case of aërial lines the effects of leakage render the results obtained from the use of inductance coils very

doubtful. With underground telephone cables very great care is necessary to so arrange the coils that overhearing between the various circuits in the cable does not result from the close proximity of the various coils.

Some experimental telephone cables, constructed for the German government, were formed by winding iron wire around the copper conductor, insulating with paper, and enclosed in a seamless sheathing of lead. Lodge and Hardie (patent 27,265 of 1903) propose iron wire of rectangular section or, in the alternative, a series of iron washers threaded tightly over the copper conductor. In November 1893 Oliver Heaviside considered this question, and expressed the opinion that if the iron were in actual and continuous contact with the copper the "skin effect" would destroy the benefit that might otherwise be derived. Probably a thick varnish applied to the copper before applying the iron would be adequate.[1]

It should perhaps be stated that M. I. Pupin was the first to make actual experiments upon the effect of introducing coils into telephone circuits.

The capacities of the various types of aërial and underground wire are as given in the following table:—

CAPACITY AND RESISTANCE OF VARIOUS TYPES OF LINE. (A. EDEN.)

Type of line.	Type of wire.	Gauge.	Capacity in m.f.'s per mile.	Resistance per mile in ohms.
Aërial	Copper	100 lb.	·0144	8·782
,,	,,	150 lb.	·0147	5·855
,,	,,	200 lb.	·015	4·391
,,	,,	300 lb.	·0153	2·928
,,	,,	400 lb.	·0156	2·195
,,	,,	600 lb.	·0158	1·464
,,	,,	800 lb.	·016	1·098
,,	Iron	400 lb.	·0157	13·32
,,	,,	450 lb.	·016	11·84
G.P. Underground	Copper	40 lb.	·3	21·959
Screened cable.	Copper	40 lb.	·125	21·959

Note on the above Table.—The table assumes average distribution of trees, and twelve wires upon the poles at an

[1] *Electrician*, p. 92, May 5, 1905.

average height of thirty feet above the ground. Where there is only one circuit upon the poles the value of the capacity given in the table should be reduced by 28%. The capacity of an open or aërial metallic circuit is five-eighths of that of a single wire circuit of the same type of wire. With underground wires it is one-half.

Example.—What is the working speed of a circuit consisting of 200 miles of 150 lb. aërial copper wire and 50 miles of G.P. underground?

Note.—The *KR* of a mixed circuit is the product of the total resistance and total capacity—not the sum of the *KR*s of the separate sections. Also, where the circuit is a mixed one, *i. e.* partly open and partly covered, the lower speed constant is taken.

Res. of 200 miles of 150 lb. copper = 1071ω
„ „ 50 „ „ G.P. = 1098ω

Total resistance = 2169ω

Capacity of 200 miles of 150 lb. copper = 2·94 m.f.
„ „ 50 „ „ G.P. = 15· m.f.

Total capacity = 17·94 m.f.

$\therefore$ *KR* of circuit $= 2169 \times 17{\cdot}94$

$$\text{Speed of working} = \frac{12{,}000{,}000}{2169 \times 17{\cdot}94}$$

= 308 words per minute.

A working speed of 400 words per minute is obtainable through the following lengths of line of each class:—

150 lb. copper wire aërial line . .	590 miles.
100 lb. „ „ „ „ . .	487 „
450 lb. iron „ „ „ . .	363 „
400 lb. „ „ „ „ . .	291 „
G. P. underground line . . .	83 „
Screened paper cable 40 lb. . .	128 „

Since the length of the circuit enters into both the total capacity and the total resistance, it will be obvious that,

with any given type of line, the speed of working is inversely proportional to the square of the length of the circuit. For instance, the *KR* of 100 miles of G.P. underground is 68150 and that of 50 miles 17037·5, hence the working speed of the latter circuit is four times as great as that of the former.

With underground lines the speed of working of a metallic circuit is the same as that of a single wire between the two stations, the reason being that whilst the resistance of the circuit is doubled its capacity is halved by the addition of the second wire. With aërial lines the speed of the metallic circuit would be less than that of the single wire.

The same *KR* underground admits of a *greater* proportionate Wheatstone speed, the exact value depending upon the dielectric. Generally speaking india-rubber gives a lower speed than gutta-percha-covered wires for the same *KR*, and the lower the speed the greater is the difference, electrification being a factor. Again, paper cables give a lower value than gutta-percha, but the screened conductor types give higher speed than even twisted metallic circuits in a paper cable.

It is also found that duplex circuits, whether bridge or differential, give a speed which is slightly less than two-thirds of the highest speed obtainable under the best conditions for simplex circuits.

Hughes' working is equivalent to Wheatstone at 40 words per minute, hence it may be worked at full speed when the *KR* does not exceed 300,000.

Theory of Repeater.

Repeaters are employed to increase the working speed of a telegraph circuit. If the speed upon a circuit, wholly of underground or wholly aërial line, is 100 words per minute, then the speed obtainable upon either half of the circuit, when divided in the centre, is not twice but 2^2 times 100, *i. e.* 400, words per minute. Where the circuit consists of short sections of underground, a long open line, and then a section of submarine cable (such as that which connects England and Ireland), a repeater is introduced as near to the cable as possible. This has the effect of dividing the line into two sections, the working speed of either of which

is considerably more than that of the whole circuit. The repeater serves to receive and retransmit the signals, therefore the speed of working is that of the section of highest *KR*, but with a very small reduction due to the mechanical inertia of the moving parts of the repeating apparatus. With a G.P. underground line 330 miles long the working speed is 25 words per minute. A repeater introduced in the centre increases this to 100, whilst two repeaters placed respectively one-third and two-thirds of the distance from either terminal gives 225. Three repeaters dividing the line into four equal sections would raise the

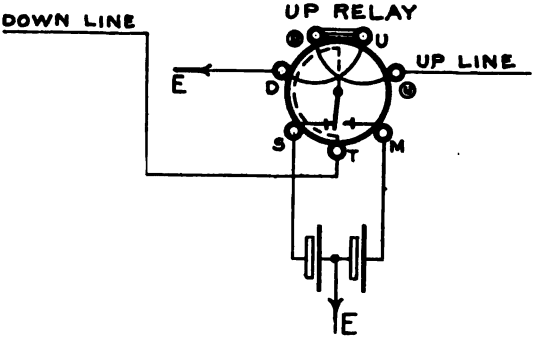


FIG. 295.—Principle of simplex repeater. Up-station sending.

theoretical speed to 400 words per minute. With Wheatstone circuits it is not usual to introduce more than two repeaters, save in very exceptional circumstances.

From what has been said it will be seen that the ideal position for a repeater is the centre of the *KR* of the circuit. Where more than one repeater is employed, they should be placed so as to divide the circuit into lengths of approximately equal *KR*.

PRINCIPLE OF SIMPLEX REPEATER.

The general principle of a simplex repeater is illustrated in Figs. 295 and 296. The former figure indicates the arrangement required to enable an up to signal to a down station, whilst the second figure shows a down sending to an up station.

The up line is joined through a relay to earth, and the tongue of this relay is connected to the down line, *S* and *M* being joined to a divided battery. The tongue of the relay is maintained against *S* by the spacing current from the up station, and a negative current from the left half of the battery therefore passes to the down station. When the up station depresses his key the tongue of the relay moves over to *M*, so transmitting a positive current to the down station which produces a mark at the down station.

In Fig. 296 the down line is terminated through a relay and the up line connected to *T*. It will be observed that the down line is joined to the down side of the relay and

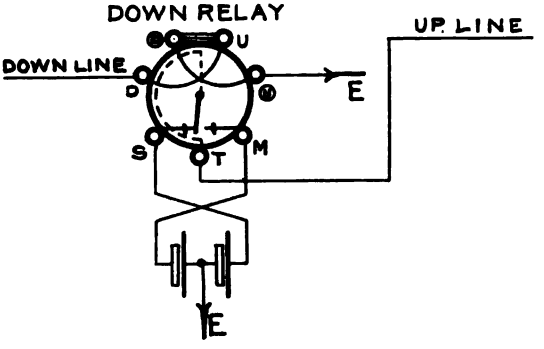


FIG. 296.—Principle of simplex repeater. Down-station sending.

that the battery connections are reversed to those of the previous figure. A down station with the key depressed sends out a negative current to line. This current causes the relay to mark and so to transmit a negative current to the up station.

In practice it is necessary to arrange that the terminal stations may work together in either direction. Since the relays are of the ordinary Post Office pattern, it will be seen that (Fig. 295) even where there is no current passing through the up relay from the up line, there will still be a current upon the down line, its direction being either "spacing" or "marking" according to whether the relay has a spacing or a marking bias, or, if the relay be of neutral adjustment, whether the tongue was left on the spacing or marking

side by the current last sent through the relay. Similar remarks apply with equal force to the down side (Fig. 296). It is therefore necessary to provide an automatic device which will establish the conditions shown in Fig. 295 when the up station turns his switch to "send," and those of Fig. 296 when the down station's switch is turned. This requirement is met by the use of two automatic switches controlled by two neutral relays, which are respectively inserted in the up and down lines, in series with the transmitting relays.

Automatic Switch.

The appearance of the automatic switch is shown by

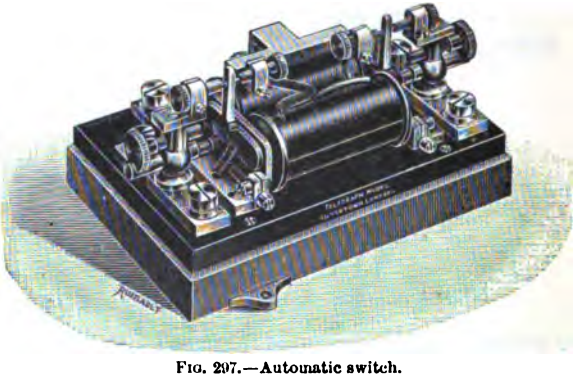


Fig. 297.—Automatic switch.

Fig. 297 whilst its connections are apparent from Fig. 298. It consists of an electromagnet with two armatures, each of which plays between two contact points. When energized, the armatures are attracted, and the levers make contact with the inner stops. The coils are shunted by a non-inductive resistance equal in value to the resistance of the coils. This shunt renders the action of the switch very sluggish—a condition which will be shown to be necessary. If the current through the coils is momentarily stopped and then re-established the armatures will not break their connections, since the E.M.F., due to the self-induction of the coils, produces a current through the coils and shunt. As the resistance of the shunt is equal to that of the coils the best

conditions for the production of a prolonged effect have been provided.

Simplex Repeater.

A galvanometer of the differential pattern, with its coils in parallel, is included in each line. In order to provide for communications between the repeater and terminal stations each line passes through the two lower terminals of a single current key with switch, the battery power being obtained

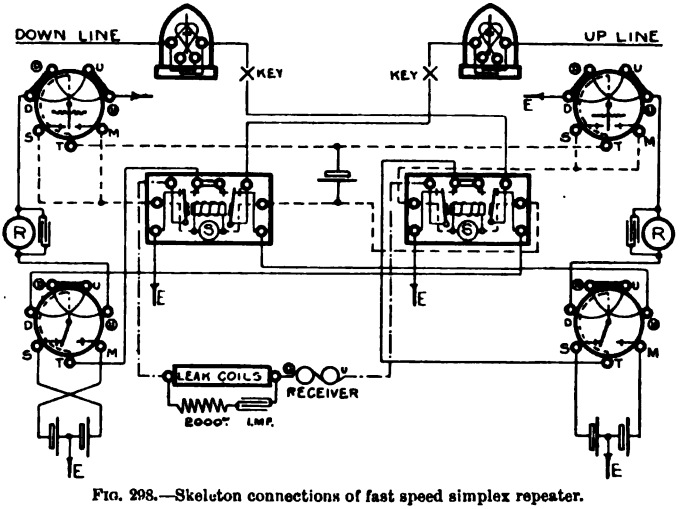


Fig. 298.—Skeleton connections of fast speed simplex repeater.

by teeing the main batteries upon either side to the *Z* and *C* terminals of the keys.

In the sketch of the connections (Fig. 298) it will be observed that a shunted condenser is placed in series with the two relays upon either side of the repeater. Its function is, as in ordinary Wheatstone working, to hasten the formation and to prevent prolongation of the signals.

A Wheatstone receiver, with a sounder and battery connected to the local, together with an adjustable resistance and shunted condenser device, is provided for observing the signals sent out by the transmitting relays.

The *S* and *M* contacts of the neutral relay (coils in parallel) are connected together to the one side of the coils of the automatic switch, the other side being joined through a local battery, consisting of ten Large Daniell or four Bichromate cells, to *T*. The local circuit is normally disconnected, owing to the central position of the relay tongue, but it is completed when the tongue moves over to either *S* or *M*. If now a series of signals pass through the neutral relay, the tongue will move from side to side in accordance with them. Since the automatic switch has been made sluggish in action by the addition of the shunt, the momentary disconnections which take place whilst the tongue is travelling from *S* to *M*, or *vice versa*, are not of sufficient duration for the armatures to be released. Hence, the automatic switch remains closed so long as a continuous mark or a continuous space is formed upon the auto-relay.

The relays, galvanometer, key, automatic switch, shunted condenser, and batteries are termed "Up" or "Down" according to whether they are in connection with the up or down lines. The neutral relays are invariably termed "auto" relays in contradistinction to the "transmitting" relays.

Path of Current.

When the down station turns his switch a positive current passes along the line to the repeater station, where it passes through the down galvanometer, through the down transmitting relay (coils invariably in series), shunted condenser and down auto-relay (coils in parallel) to earth. The down auto-relay closes the auto-switch, which connects *T* of the down transmitting relay to the up line. As the current from the down station passes through the relays in the direction *D* to *U* a positive current is sent out through the contacts of the down auto-switch and through the up galvanometer to the up line. A series of signals causes both the down relay tongues to move in accordance with those signals, and, as the momentary disconnection of the auto local circuit does not release the armatures, the signals are accurately transmitted to the up station.

If the down station turns his switch to receive and the up station commences to send, the latter's current passes

through the up galvanometer and up relays to earth. The local circuit of the up auto is closed and the up transmitting relay consequently repeats the signals received to the down station.

Inspection of the figure will show that the receiver and leak coils are connected to the up or down line according to whether the repeated signals are being sent out on the up or the down line. The receiver, therefore, serves for observing the character and condition of the marks leaving the repeater station. The adjustable resistance coils in series with the receiver have a total resistance of 20,000$^{\omega}$, and by this means the current through the leak circuit may be regulated. The prime purpose of the coils is to reduce the current through the leak receiver to the lowest possible value which is sufficient to reliably work it. In this way every small irregularity will be made apparent, whereas, with a stronger current flowing, the defect is frequently covered up. The resistance of the leak circuit has but little effect upon the value of the current received at the terminal stations. Upon a circuit of 5000$^{\omega}$ resistance with a battery resistance of 500$^{\omega}$ the current received is reduced by less than 6% when the leak circuit resistance is reduced from 20,000$^{\omega}$ to 5000$^{\omega}$.

A 1 m.f. condenser is placed in series with a 2000$^{\omega}$ resistance coil and the combination joined across the terminals of the leak coils, in order to balance the self-inductance of the receiver, and so reduce the tendency to sparking at the contacts of the transmitting relays.

Adjustments.

In adjusting the auto-relay care should be taken that the least possible tension is given to the springs. When so adjusted there are, on the cessation of the current, two forces tending to restore the tongue to the midway position, since one spring is in compression, and therefore assists the spring which is in tension. When a considerable amount of tension is placed upon the springs, both are in tension when deflected, and uncertain working at once results. Where the adjustment has been carefully made it is by no means unusual for the relay to work for six months without re-adjustment.

In Chapter V it was pointed out that, in a later form of relay, the spiral springs had been discarded in favour of a flat spring connected to the tongue. This type of instrument is far easier to adjust, but experienced repeater clerks prefer the older form on account of its wider range and greater stability of adjustment.

The working speeds of all the most important Wheatstone circuits are tested each day, in order that the adjustments may be verified or corrected before the heavy traffic commences. The maximum working speed, known as the "standard speed" of each circuit, is stated at the time of its installation.

Prior to commencing the daily speed trials—either simplex or duplex—the contact points should be well burnished, closed up to the short circuiting point, opened by the smallest possible amount, and the tongue set neutral. The smaller the play of the relay tongues the higher is the working speed of the relay—this has, however, already been noted in Chapter V.

Faults.

Whilst it is scarcely possible to schedule every fault which can occur upon a repeater-board, there are a few defects of common occurrence which may with advantage be here recorded. In each case where the neutral relay is concerned the note as to the cause refers to the spiral spring type. Where the newer form is in use, the terms "too much tension" and "too little tension" should be read "spring too short," and "spring too long" respectively.

Fault. *Auto-switch jumping whilst stations working.*

Cause. (1) Too much resistance in the rheostat,
(2) Contact points of auto-relay too wide apart,
(3) Contact points of auto-relay dirty,
(4) Too much tension on spiral spring of auto-relay,
(5) Auto-battery weak,
(6) Contact or intermittent earth on line, or
(7) Fault in sender's key.

FAULT. *Auto-switch jumping whilst circuit at rest.*

CAUSE. (1) Too little tension on spiral springs of auto-relay, or
(2) Contact points too close, or
(3) No resistance or insufficient resistance in rheostat.

This fault might also be due to lightning discharges.

FAULT. *Auto-switch sticking whilst circuit at rest.*

CAUSE. (1) Faulty adjustments of spiral springs of auto-relay.
(2) Faulty adjustment of auto-switch armatures.

When a station reports a current being left on at the repeater a glance at the galvanometers will usually suffice to show whether this is so or not. If both galvanometers show a deflection, the current is probably coming into the repeater from one side or the other. To make certain of this, put over both switches to " send," and if the armatures of the auto-switches are at once released the fault is not at the repeater. If, however, the levers fail to return to their normal position, the fault is with the repeater and must be at once attended to.

When the current received is very weak and there are no means of increasing it, it will probably be found necessary to increase the sensitiveness of the auto-relay by decreasing the tension of the spiral springs.

FAULT. *Signals running together or failing.*

CAUSE. (1) Line fault,
(2) Sender's key faulty,
(3) Misfitting slip, or
(4) Contact points of transmitting relay dirty.

FAULT. *Sending batteries short circuiting.*

CAUSE. (1) Contact points closed up touching the tongue,
(2) Line to earth very near,
(3) Lightning protector short circuited, or
(4) Key screwed down.

This fault would cause the indicator bell to ring.

FAULT. When an office advises that they are *unable to gain*

the attention of the repeater clerk, and it is found that no call is being received, the key switch should be put to "send," and if the terminal station's current is received on the galvanometer the fault is likely to be in:—

(1) The right-hand lever of the auto-switch. If not there—
(2) Examine switch of key,
(3) Arms of rheostat,
(4) And all other connections of the incoming current.

FAULT. *Weak signals in the leak circuit* might be due to—

CAUSE. (1) Too much resistance in leak coils.
(2) Faulty receiver adjustment, or—
(3) Earth on line, close up to repeater. This latter fault might cause the indicator bell to ring.

FAULT. *Signals unreadable at terminal station although good marks are obtained on the leak receiver.*

CAUSE. (1) Line fault, or
(2) Instrument fault at the distant station, or
(3) Right-hand lever of auto-switch not making good contact. (This is somewhat improbable.)

An earth fault is frequently caused by lightning discharges short circuiting the protectors.

When a fault appears, it is unwise to alter any adjustment until the nature of the defect is known with certainty.

DUPLEX REPEATER.

The neutral relays and auto-switches are not needed in duplex working, and therefore the principle and the skeleton connections are simpler than those of the simplex repeater. The tongues of the up and down transmitting relays are respectively connected to the splits of the down and up relays. The compensation circuits are arranged as in ordinary duplex working, and the condensers, rheostat, retardation and condenser coils are denoted by "R" in the conventional diagram given in Fig. 299.

At the up and down offices the skeleton connections, when the keys are at rest, are given in order to correlate

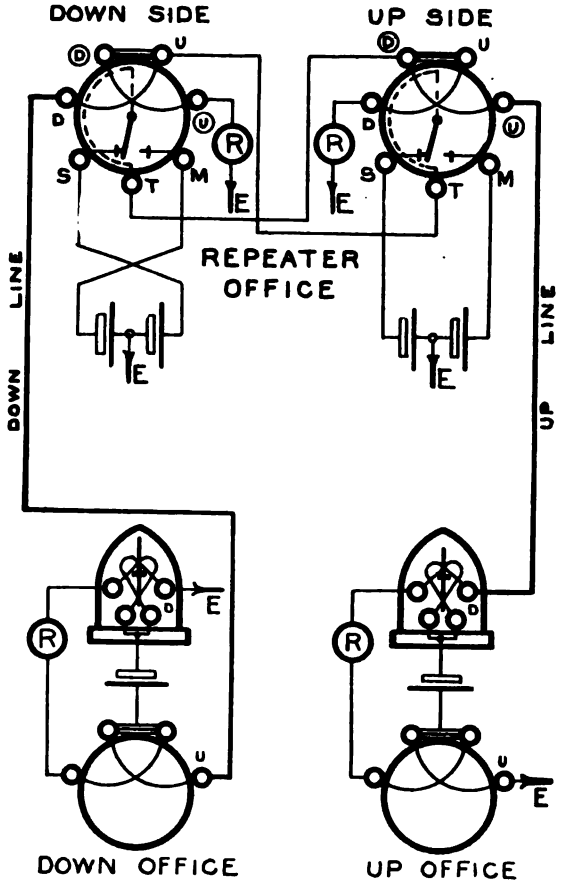


FIG. 299.—Skeleton connections of duplex repeater showing terminal stations with their keys at rest.

the various parts of the complete circuit. It is assumed that all four compensation circuits have been balanced as in ordinary duplex working. The position of the tongue

of the up relay depends upon the position of the up station key, whilst the down relay is similarly controlled by the down office. The path of the current upon the up side is—from the positive pole of the down battery through the circle coils of the up relay (direction *D* to *U*), through the up line, and through the right coil, battery, and circle coil of the relay (direction *D* to *U*) at up office to earth. The tongue of the up transmitting relay is thus held over to *S* by the preponderance of the line over the compensation current. The compensation currents at the up relay and at the up office should require no comment.

The path of the current from the down office is from its battery, through the relay (direction *D* to *U*), through the line, through the plain coil of the down relay (direction *D* to *U*) to the tongue of the up transmitting relay, joining with the negative half of the battery, to earth, through the right coil of the down relay back to the down office battery. The tongue of the down transmitting relay is thus held over to *S*.

If the up office key is depressed the tongue of the up transmitting relay moves over to *M*. This reversal causes the battery to oppose that at the down office, and a mark is made by the down office compensation circuit. It will be observed that the down transmitting relay still spaces, and a space is therefore registered at the up office. To go over all the possible combinations is merely to repeat a considerable portion of Chapter VII. The important point to be observed is that the key at the up office determines the position of the tongue of the up transmitting relay, whilst the down key controls the tongue of the down relay.

The duplex and single switch is of the 8-bar type, and is equivalent to eight two-way switches operated by a single lever or handle. Its functions in changing from simplex to duplex are as follows:—

1. To disconnect the neutral relays.
2. To place the galvanometer coils in series with the relay as in Fig. 283.
3. To tee the leak receiver and leak relay to the *T* terminals of the transmitting relays.
4. To place the keys in series with the split wires for balancing and speaking purposes.

It is essential that the repeater station shall be able to observe the condition of the marks sent out upon either side, so that either office shall always be able to gain the attention of the relay clerk. This is provided for by means of the leak switch, which connects the leak receiver and leak relay to the up and down transmitting relays in accordance with the position of the peg. In this way, the receiver may be used to observe the marks sent out upon either side, whilst the two sounders, attached to the leak receiver and relay, serve to indicate calls. In simplex working either the receiver or the relay may be joined up as in Fig. 298.

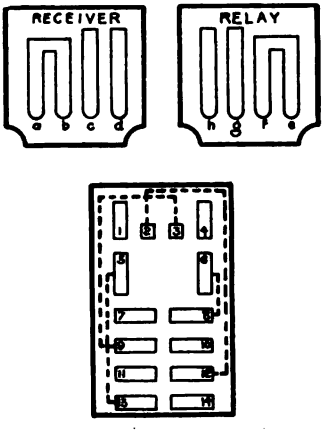


FIG. 300.—Peg switch used in connection with the leak circuit of duplex repeaters.

The switch consists of fourteen mounted springs (marked 1 to 14 in Fig. 300) and a peg bearing four springs upon either side. The peg may be inserted either vertically between contacts 7 to 14 or horizontally between contacts 1 to 6. The two sides of the peg are marked "receiver" and "relay" respectively, and the switch is so joined up that the engraving upon the peg denotes the sides to which the receiver and relay are connected when the peg is placed vertically. When in the horizontal position, the engraving upon the front side of the peg indicates whether the receiver or relay is in circuit.

The connections of the leak circuit and switch are indicated in Fig. 301. When working duplex, the peg is

inserted vertically, and when the relay side faces the left the following connections are made:—7 to 8 by *h* and *d*, 9 to 10 by *g* and *c*, 11 to 13 by *f* and *e*, 12 to 14 by *b* and *a*.

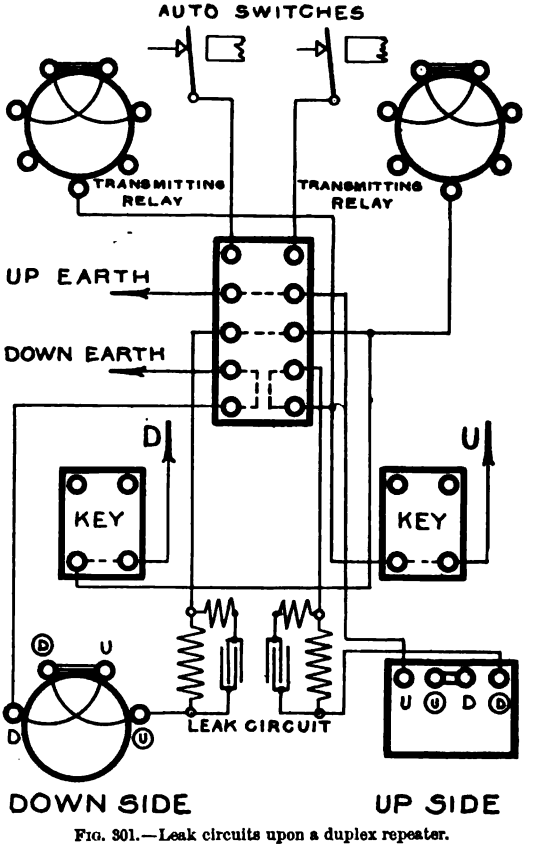


FIG. 301.—Leak circuits upon a duplex repeater.

The springs *a* and *h* and *b* and *g* are respectively connected together by screws passing through the body of the peg.

Reversal of the peg joins 7 and 9, 8 and 10, 11 and 12, and 12 and 14, so connecting the receiver to the down and relay to the up transmitting relay.

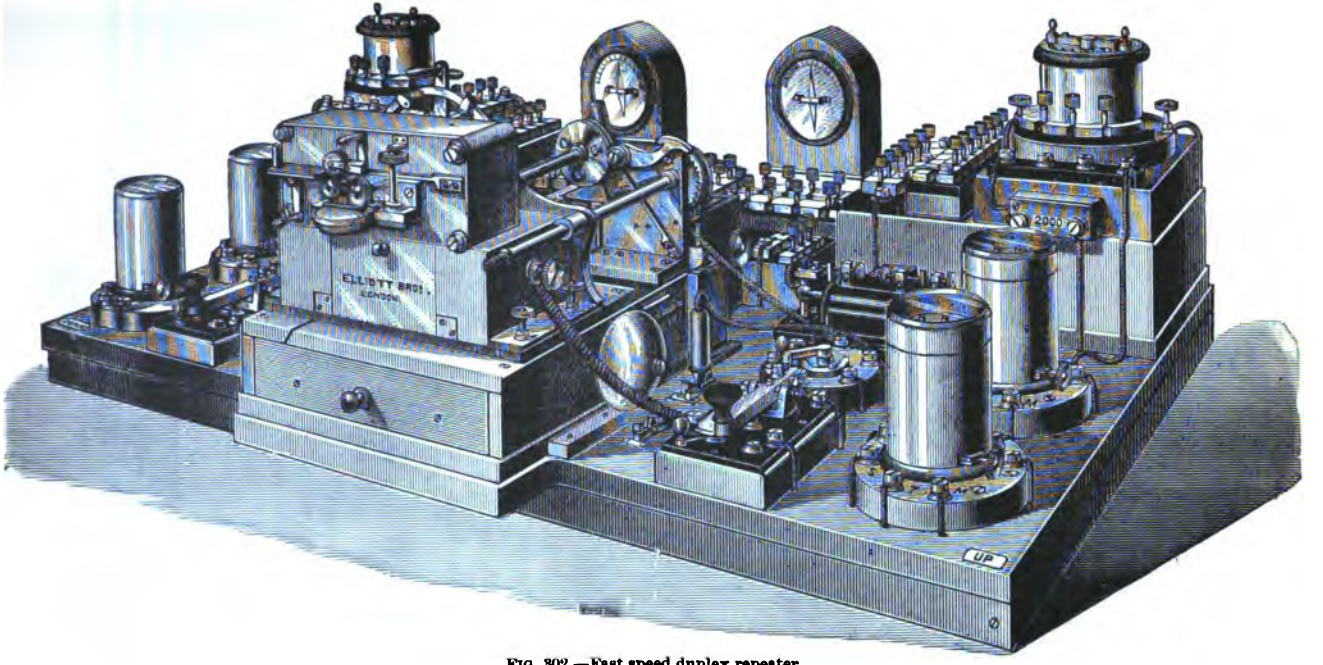


FIG. 302.—Fast speed duplex repeater.

At simplex the peg is placed horizontally and with the receiver side of the peg facing the front, 1 and 2 and 4 and 6 are joined.

The general arrangement will, however, be quite apparent from Fig. 301.

Two battery resistance coils and 6-terminal 2-position switches are provided, as in Wheatstone duplex sets, for balancing purposes. The rheostat, condenser, and its timing resistances upon each side are used as the shunted or reading condenser in simplex working. Two sets of leak

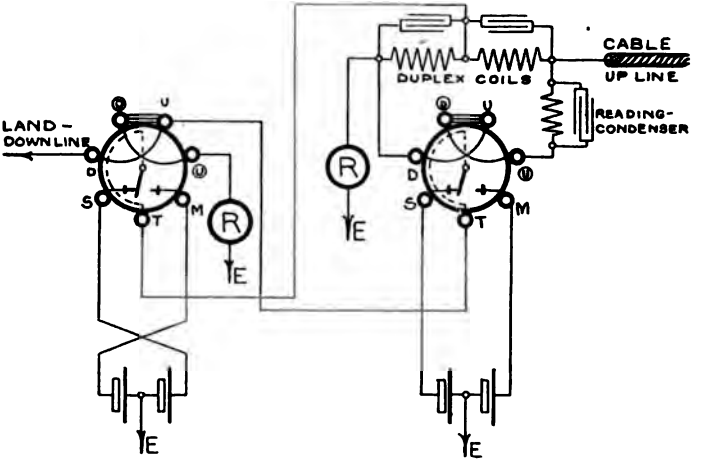


FIG. 303.—Skeleton connections of a duplex repeater working upon the bridge method on the cable side.

coils placed in a single box are used in conjunction with the leak relay and receiver, and each is supplemented by the usual leak condenser, etc., as shown in Fig. 301.

A view of a duplex repeater is given in Fig. 302, but in later forms the pegs, cords and switch springs in the leak circuit are replaced by a peg switch of the type shown in Fig. 304.

DUPLEX REPEATER FOR CABLE CIRCUITS.

Cable circuits are usually worked upon the bridge duplex system in order to obtain a higher speed than is possible

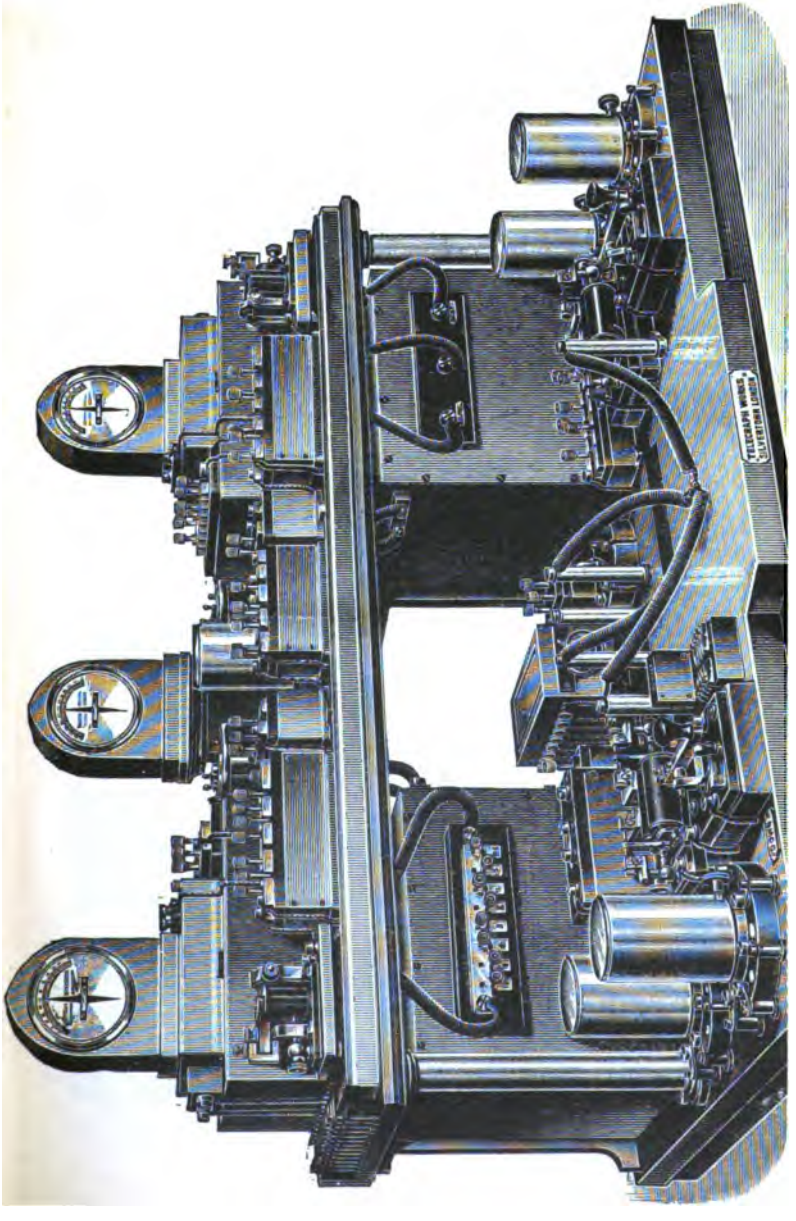


Fig. 304.—Duplex repeater board for bridge working upon the cable side.

with the differential duplex; but since the speed of the land line is invariably greatly in excess of that of the cable, the land line is worked as a differential duplex in order to economize battery power. This arrangement contains no new principles, and it is believed that the skeleton diagram given in Fig. 303 is sufficiently explicit. A view of such a repeater is given in Fig. 304, and it may be pointed out that the receiver is placed in a similar position to that shown in Fig. 302, and that the sounders, etc., are placed upon the shelf above the board. The large condensers required for balancing and for signalling on the cable side are mounted upon the up and down sides of the board, whilst the land line balancing condenser is fixed upon the shelf. The third galvanometer is in the leak circuit—an arrangement which is being generally adopted upon all new circuits.

FORKED REPEATERS.

There are cases in which it is necessary to repeat to two or more offices situated in opposite directions; for example, London transmits news to Belfast and Cork with the aid of a forked repeater at Dublin. This object may, of course, be accomplished by using an ordinary simplex repeater with the Dublin-Belfast and Dublin-Cork lines connected together to the down side. In this case it will be obvious that, since Cork and Belfast are both down offices, the signals sent by Belfast would be received reversed at Cork, and Cork's signals would be reversed at Belfast, but both offices would, of course, read London correctly, and, similarly, London would be able to read both. The forked repeater was designed to enable the "fork" offices to read each other's signals, and, in the apparatus about to be described, provision is made for Wheatstone working from all offices.

By means of a 6-bar switch the forked repeater may be converted into a simplex repeater of the type illustrated in Fig. 298. It will, however, suffice to indicate the principle of the arrangement by means of a skeleton diagram.

The forked repeater contains three galvanometers, three transmitting, three auto-relays, three auto-switches, and two relaying sounders.

PATH OF CURRENT.

Referring to Fig. 305, it will be seen that a current from the up station passes to earth *viâ* the right-hand lever of auto-switch 1, up transmitting relay, rheostat, and up auto-relay. The latter relay closes auto-switches 2 and 5. The current from the up transmitting relay passes to the down line 1 *viâ* the right-hand lever of auto-switch 2 and to down line 2 *viâ* the left-hand lever of auto-switch 5. A portion of the total current also passes through the leak circuit *viâ* the left-hand lever of auto-switch 2. A current from down line 1 passes to earth *viâ* the right-hand

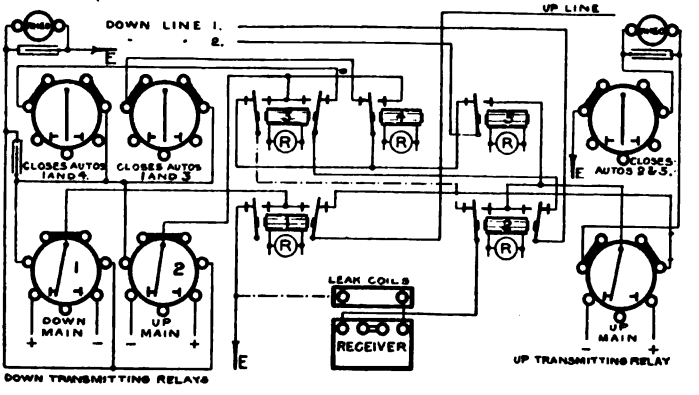


FIG. 305.—Principle of forked repeater.

levers of auto-switches 2 and 3, the left-hand down auto-relay in parallel through the down transmitting relays and the rheostat. The left-hand auto-relay closes auto-switches 1 and 4 and the current from the left-hand down transmitting relay passes to the up line *viâ* the right-hand lever of auto-switch 1, whilst the current from the right-hand down transmitting relay passes to down line 2 *viâ* the left-hand levers of auto-switches 4 and 5 and to the leak circuit *viâ* the left-hand levers of auto-switches 4, 3 and 2.

A current from the down line No. 2 passes to earth *viâ* the right-hand levers of auto-switches 5 and 4, right-hand down auto-relay, in parallel through the down transmitting relays and the rheostat. The right-hand down auto-relay

closes auto-switches 1 and 3, and the current from the left-hand down transmitting relay passes to the up line *viâ* the right-hand lever of auto-switch 1 as in the case of the current from the down line 1, whilst the current from the right-hand down transmitting relay passes to down line No. 1 *viâ* the right-hand levers of auto-switches 3 and 2 and to the leak circuit *viâ* the left-hand levers of auto-switches 3 and 2.

It will thus be seen that the signals are "straight" to all stations, and that the down stations are enabled to read each other's signals.

A 6-terminal 2-position switch is added to the board in order that the condition of the signals sent out, upon either of the down lines, may be observed. The key for corresponding with the terminal stations is of the reversing key pattern, but has a send and receive switch equivalent to three mechanically connected two-way switches. This is necessitated by the fact that signals are simultaneously sent out to the three lines; one side of the key is used for the down lines, whilst the other side sends out currents upon the up line.

SOUNDER SILENCER.

The advent of the sounder silencer, which was invented by Kempe, marked a new epoch in the history of repeater stations. Prior to its advent the greatest difficulty was experienced in detecting calling signals from amongst 15 or 20 repeaters working simultaneously in a room, the dimensions of which might not exceed 15 feet square. With the silencer the whole of the local circuits containing sounders are normally disconnected, but may be joined up, as desired, at the will of the repeater clerk, or the relevant sounder may be brought into circuit by either of the terminal stations upon any repeater circuit. In order to call the repeater station the terminal office holds down the key, for from 14 to 18 seconds, and then gives the calling code signal once. In the comparatively silent room the call is at once observed and prompt attention is the result.

The electromagnets of the sounder—one magnet being required for each sounder—are placed side by side with

the jointed extension arms of each pivoted armature lever resting upon a continuously revolving wooden barrel (Fig. 306). The armature lever A carries two contact springs S_1 a S_2 playing between two contact points C_1 and C_2. The extension arm L rests upon the barrel C, against which it is held by the spiral spring S_3. The electromagnet is connected to a battery through T and S of the relay or receiver as the case may be (Fig. 307).

In the normal position, when the relay or receiver tongue is resting upon S, the armature A is attracted, which prevents the slowly revolving cylinder from pulling down the end of the brass lever. The local circuit of the sounder is thus kept disconnected, but immediately a marking current is sent through either the relay or the receiver the

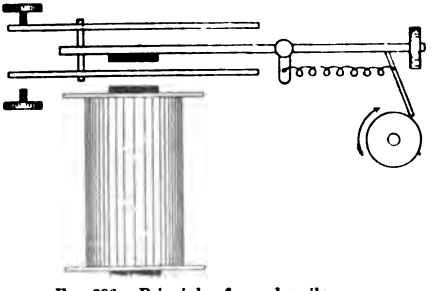


FIG. 306.—Principle of sounder silencer.

silencer magnet circuit is disconnected, and the cylinder C gradually pulls down the lever, with the result that contact is broken at C_2 and made at C_1. This completes the local circuit, and the sounder is brought into play.

The instrument is usually adjusted to bring the sounders into circuit after the terminal station has continuously depressed his key for from 14 to 18 seconds. In ordinary working the spacing currents follow the marking currents too quickly to allow the armature to rise to the full extent necessary to bring in the sounders. Should the clockwork driving the wooden barrel stop, the whole of the sounders are brought into play by the pendulum bob opening the throw-off switch, thus disconnecting all the silencer magnet circuits.

The actual connections of a sounder silencer are depicted in Fig. 307. The only point for comment is that the specially designed press-button enables the relay clerk to bring in the sounders at will by disconnecting the silencer magnets. When the right-hand button is depressed instead, the sounders are thrown out of circuit.

Circuit Silencer.

A single set of clockwork is necessary for the whole of the sounders which it is necessary to silence in any given office, and where there are several to be dealt with the sounder silencer is invariably employed. The cost of the device per circuit is extremely high where but one or two

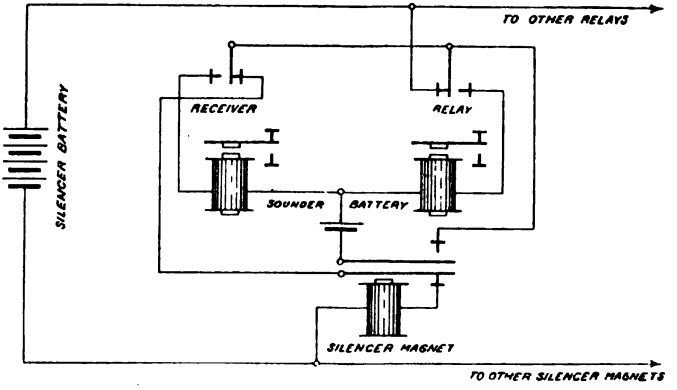


Fig. 307.—Connections of silencer magnets.

sounders have to be silenced, and accordingly a new instrument termed a "circuit silencer" has recently been designed. This instrument is also largely employed upon those circuits which are led into offices for the transmission of service messages concerning the testing of wires passing the test-boxes of the offices in question. The number of messages will not be sufficient to justify the use of a circuit for this purpose alone, and the ordinary channels may involve re-transmission, thus incurring delay.

The circuit silencer is shown in perspective in Fig. 307*a*, whilst the detail of the pneumatic regulator and valve is

shown in Fig. 307*b*. The electromagnet is connected with a local battery between *T* and *S* of the relay upon the circuit to be silenced, and therefore every spacing current causes the armature to descend. The end of the armature is connected to the centre of an oiled silk diaphragm which can move downwards quite freely by expelling the air from the chamber through the outlet valve. The air

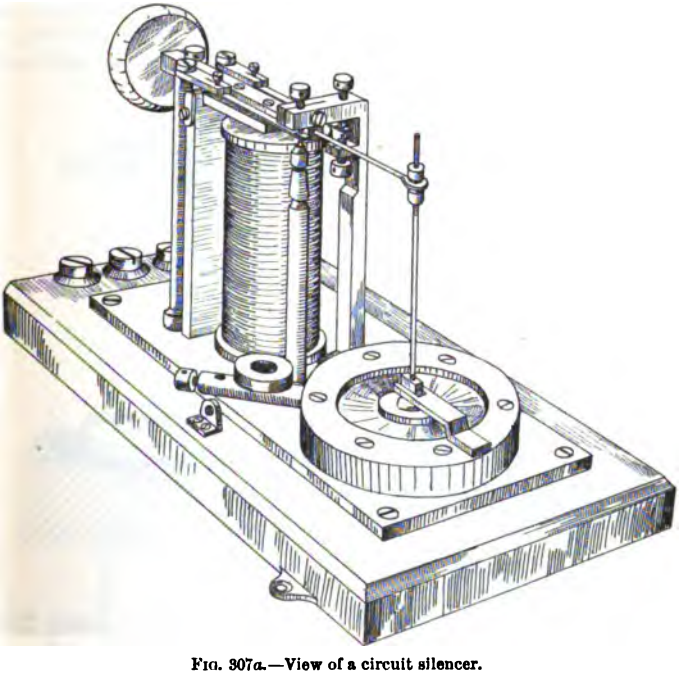


FIG. 307*a*.—View of a circuit silencer.

inlet is, however, regulated by the platinum cone, and may be made as small as is required. If the key at the terminal station is held down for about 15 to 20 seconds the chamber fills with air and the armature rises to its full extent thus bringing in the sounder. It may also be interesting to notice that the effects of residual magnetism have been employed to prevent the apparatus acting when Wheatstone signals are being sent over the circuit. The

armature is allowed to bank down on to the cores of the electromagnet, and this no doubt very greatly increases the sluggishness with which the instrument works.

External Connections of Repeater Board.

The external connections of a repeater board are shown in Fig. 308, and call for very little comment. It will be observed that a non-polarized drop indicator is included in the negative lead of each main battery. This serves to indicate a short circuit between *S* and *M* upon the relevant

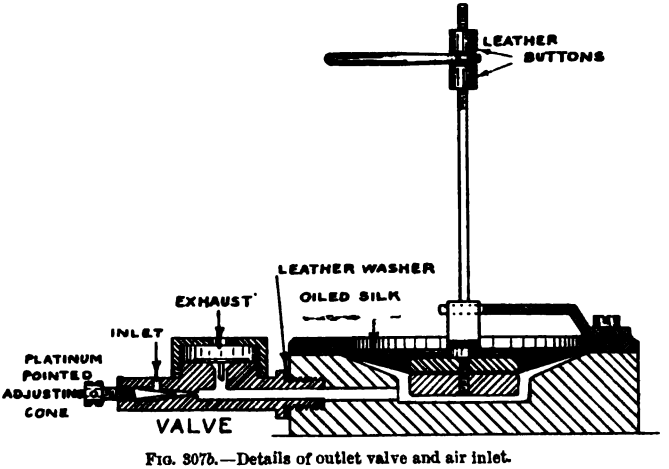


Fig. 307b.—Details of outlet valve and air inlet.

transmitting or auto-relays. The 3ω indicator (coils 25ω and shunt 3·4ω) is not actuated by the ordinary working currents, but only by the current resulting from a short circuit of the main battery through its coils.

The changes necessary where the repeaters are worked by secondary cells are sufficiently obvious from the principles laid down in the previous chapter.

Battery Power, etc.

The minimum power used upon repeaters is 100ᵛ, and where secondary cells are not in use Bichromate batteries

are employed. The auto local battery is usually 10 Large Daniell or 4 Bichromate cells, or with the secondary cell system 24', the switches being wound to suit this value.

THE HUGHES REPEATER.

The Hughes repeaters are simpler than any of those

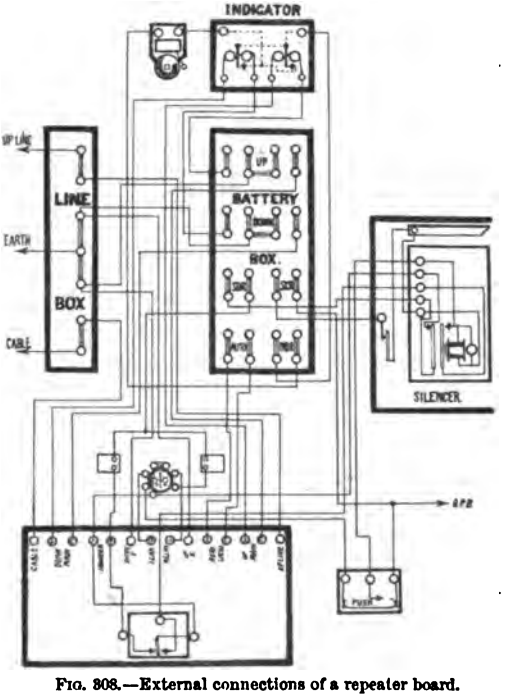


FIG. 808.—External connections of a repeater board.

previously described. The main feature is the use of a switch by which sounder apparatus may be introduced for speaking purposes. The only other point is the use of a "discharger," which consists of a relaying sounder. The coils are joined up in the local circuit of a standard relay, and when a current is sent from the up-relay a portion of the current passes to earth *viâ* the leak coils and the coils

of this discharger relay, the local circuit is closed and the armature of the relaying sounder is held down. The action of this sounder is sluggish, so that while on the cessation of the current the tongue of the transmitting relay promptly falls to the spacing side, the armature of the relaying

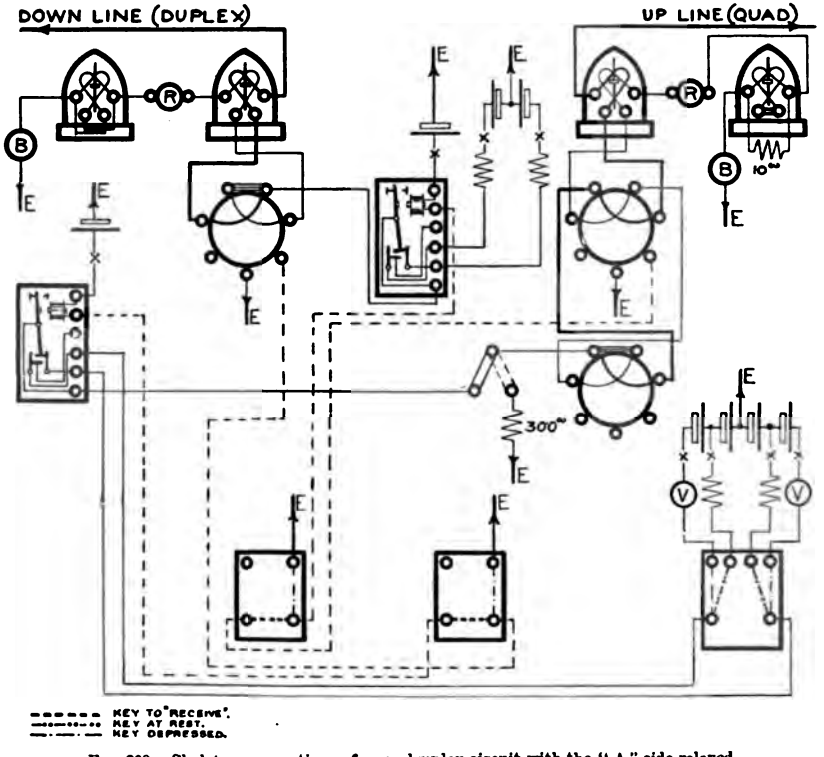


FIG. 309.—Skeleton connections of a quadruplex circuit with the "A" side relayed to a down office.

sounder is held down for an appreciably longer time, and during this interval the cable discharge passes to earth *viâ* the tongues, the spacing contact of the transmitting relay and the armature of the relaying sounder. Reference to Plate 37 of the official diagram book will make the whole action perfectly clear.

QUADRUPLEX A SIDE RELAYED.

Where a line passes through three offices *X*, *Y*, and *Z*, the *XY* section of the line is frequently quadruplexed, and the *A* side relayed to *Z* from *Y*. This gives the equivalent of an *XY* and an *XZ* duplex circuit without the necessity of two wires between *X* and *Y*. After the consideration accorded to duplex repeaters little difficulty should be experienced in following the arrangements necessary to meet this requirement. The apparatus needed, with the single exception of the pole-changer, has already been described.

Pole-changer.

The pole-changer consists of an electromagnet with a pivoted armature, the end of which plays between two contact levers. In the normal position the end of the armature lever depresses the right-hand contact lever with which it makes contact, whilst the connection between the lever and its upper point is severed. When the electromagnet is energized, the armature lever makes contact with the upper lever, and severs the connection with the lower contact point. The arrangement is depicted conventionally in the general figure of a quadruplex *A* side relayed.

Path of Current.

The skeleton connections of a quadruplex circuit with the *A* side relayed to a down office are shown in full skeleton in Fig. 310. Each relay is, of course, furnished with a sounder, but, for the sake of simplicity, these have been omitted in each case. Similarly *R* has been employed to denote the rheostat, condenser, and timing resistances, whilst *B* represents the inductance coil, mention of which was made on p. 514.

The quadruplex line is connected to the galvanometer, and the *A* and *B* side relays arranged as in ordinary quadruplex working. The local circuit of the *A* side relay is connected to a sounder, and also through the coils of the right-hand pole-changer to the 24^{v} battery. In this way the marks received upon the *A* side relay actuate the sounder, and also produce corresponding movements of

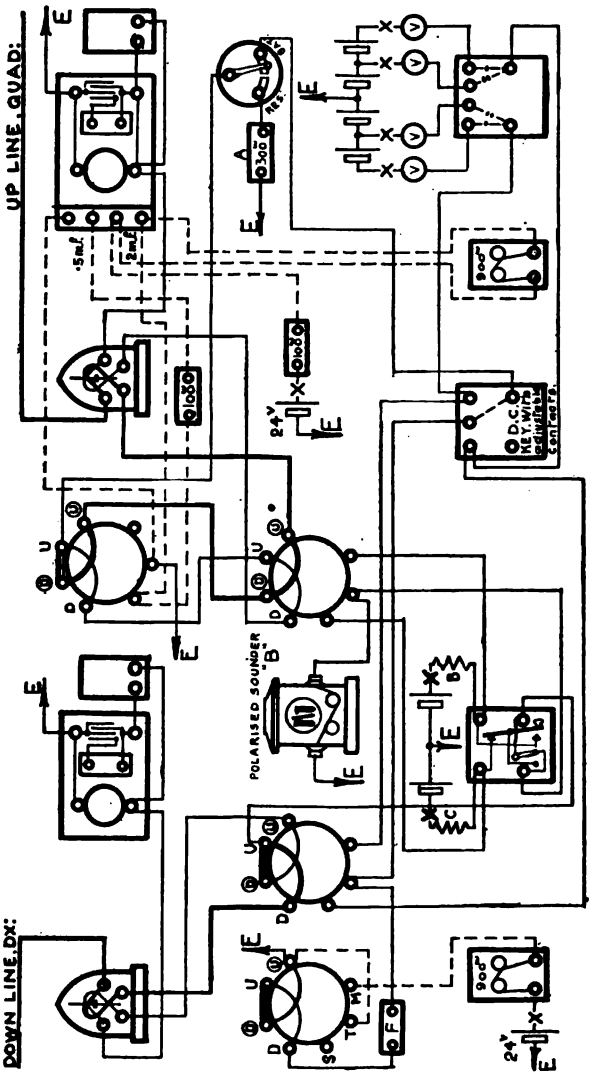


FIG. 310.—Latest arrangement for relaying the "A" side of a quadruplex circuit.

the armature of the pole-changer. This pole-changer may be regarded as a double current key automatically operated by the closing of the local circuit of the *A* side relay.

In a like manner the left pole-changer is operated by the relay on the duplex line. Now, the 6-terminal reversing key determines the power supplied, whilst this pole-changer determines its direction. The levers of the pole-changers are joined to the splits of the duplex, and of the quadruplex circuits. The *A* side marks are thus repeated to the down or duplex station, whilst its marks are repeated to the quadruplex circuit.

It will be observed that the circuits of the pole-changers are taken through two "single current keys with switches." This enables the pole-changers to be operated in accordance with the marks sent out, and so serves for balancing purposes, or if necessary the circuit may be worked as two independent duplex and quadruplex circuits.

A galvanometer, coils in series and shunted by 10^{ω}, has been placed in the quadruplex compensation circuit for measuring the current when required. The power required for duplex working is about one-third of the full quadruplex power, and therefore a galvanometer with its coils in parallel is adequate to the needs of the duplex circuit.

At offices where secondary cells are not in use the same arrangements are made save that a 13-cell bichromate battery is used for each local circuit, the fuses omitted, and the lamp resistances replaced by metal-cased resistance coils. The split batteries are still retained.

At an up office, relayed to another up office, the wires on the upper and on the lower terminals of the quadruplex circuit line galvanometer, *D* and *U*-circle on the *A* side relay, the battery wires upon the second and third terminals of the pole-changer, and the two upper wires upon the duplex circuit line galvanometer.

NEW QUADRUPLEX A SIDE RELAYED.

The latest method of relaying the *A* side of a quadruplex circuit is shown in Fig. 310, and chiefly differs from the previous method in the substitution of polarized standard relays for pole-changers. Although a momentary short

circuit is preferable to a momentary disconnection in the sending circuit, the alteration has proved to be beneficial. This result is undoubtedly due to the fact that the weight and amplitude of motion of the moving system are far less in a relay than in a pole-changer.

A polarized sounder is connected in leak with the tongue of *A* side transmitting relay for the purpose of affording a means of checking the adjustment of that relay, and so ensuring that satisfactory signals are sent on to the duplex line. The relay connected to the tongue of the duplex relay is used to form the signals from the duplex circuit upon the sounder.

By turning the switch of the *DC* key to "send" quadruplex working may be resorted to upon the up-line, whilst the duplex circuit may be independently worked by means of the single current key with switch. This facility is frequently of considerable practical value, and it is obtained without any sensible addition to the apparatus essential for relaying the "*A*" side since extra keys must necessarily be provided for balancing purposes.

QUADRUPLEX REPEATER.

During the past few years quadruplex working has been greatly extended and, in order to work over very long lines, or rather lines having a high *KR*, it became necessary to design a quadruplex repeater. The chief difficulties are experienced in dealing with the *B* side, since an apparatus which will perform the functions of the 6-terminal reversing key is required. One instrument of this character, termed an incrementer, and illustrated in Figs. 310*a*, 310*b*, and 310*c*, was recently introduced. It consists of a vertical electromagnet acting upon a soft iron armature attached to a divided lever pivoted at its lower extremity. The upper end of this lever is furnished with two adjustable contact screws (Fig. 310*b*), which are normally clear of the two pivoted contact levers. When the electromagnet is energized the divided lever moves forward, establishes contact with the pivoted levers, and finally moves both forward, thus breaking the connection existing between the levers and their contact points. It will thus be seen that the

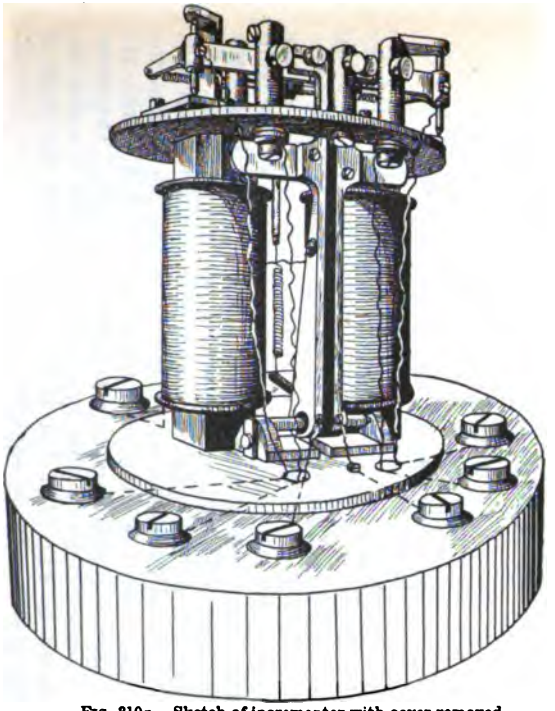


FIG. 810a.—Sketch of incrementer with cover removed.

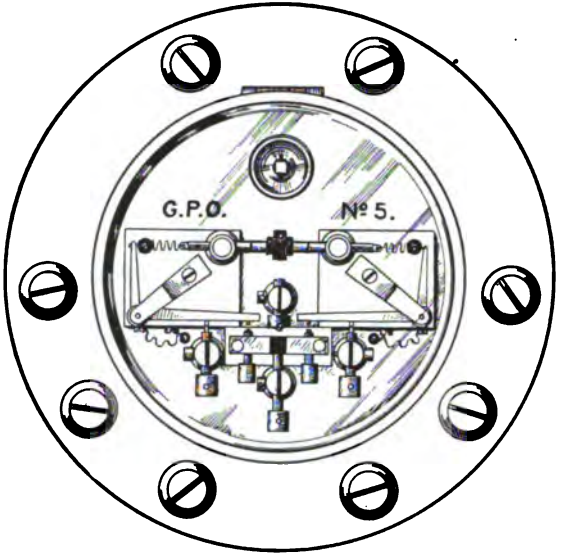


FIG. 810b.—View of top of incrementer.

incrementer provides for a momentary short circuit whilst the levers are moving.

If now a standard relay is used to determine the direction of the current whilst the incrementer determines its magnitude, a quadruplex repeater may at once be designed. The local circuit of the up *A* relay would operate a standard relay, whilst the up *B* relay would operate the incrementer, the tongue of the *A* relay being connected to the split of the down *B* relay. Similarly the down relays would operate a relay and an incrementer, the tongue of the former being connected to the split of the up *B* relay.

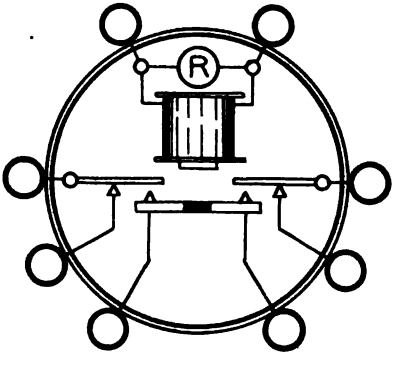


FIG. 310c.—Diagrammatic representation of an incrementer.

By modifying these arrangements somewhat it is quite easy to provide for an office *P* to work duplex to *R* and *S* having a single wire from *P* to *Q* and one each *Q* to *R* and *Q* to *S*.

It has been found that, owing to the inertia of the moving system, the type of incrementer depicted is unsuitable for very long circuits, and more especially is this the case when Wheatstone working is required upon the "*A*" side. A double-tongued relay was tried for the purpose, but the adjustments were found to be too fine, and at the present time two separate relays connected in series are being used with eminently satisfactory results. The skeleton connections of this type of quadruplex repeater are shown in Fig. 310*d*, but it is quite possible that some of the details may be slightly modified.

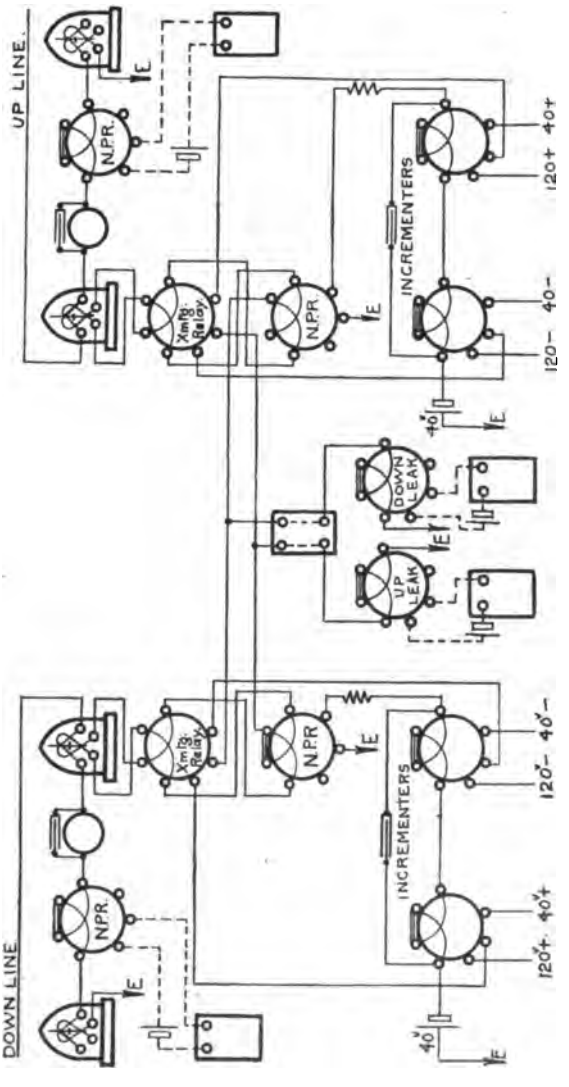


FIG. 3104.—Skeleton connections of a quadruplex repeater.

It will be observed that a condenser is placed across the relays used as incrementers, the object being to avoid irregularities due to the "*B*" kick effect. Leak circuits are also added for observation of the signals sent out upon each side. Suitable keys are provided for balancing and for speaking purposes. It will, however, at present stage be sufficient to indicate the general principles involved. In the final arrangement switches will no doubt be introduced for converting the set for simplex working, whilst the incrementing device will be modified possibly by using two polarized armatures operated by a single pair of electromagnets.

The *A* side signals passing out are judged by the marks upon the up and down leak relays, whilst the *B* marks are observed with the aid of the non-polarized relay placed in each compensation circuit.

CHAPTER XVIII

THE TEST BOX AND PROTECTIVE DEVICES.

PART I. THE TEST BOX.

Principle and General Arrangement.

THE test box, which is one of the most important adjuncts of a telegraph office, provides a point from which the various tests and circuit changes may readily be made. The principle of each of the many forms in daily use is the same, and since the old form is, in some respects, simpler and easier of comprehension, and is also in very extensive use at the present moment, the general arrangements of these boxes will first be described and the various types related to them. In the course of time, the old form will, of course, gradually disappear in favour of the later and more compact type.

In very small offices where there are but two or three instruments the wires are directly connected to the apparatus. It is only when through wires are also led into the office for testing purposes that the cost of a test box is warranted in such a case. Ordinarily the amount of testing required upon these minor circuits is very small indeed, whilst circuit changes and crosses are practically unknown. The number of cases in which the whole of the required tests cannot be made from the test box at the distant or large office end of the circuit is insignificant.

The older form of test box consists of a suitable number of terminal screws, mounted upon a vertically placed wooden base-board, and suitably connected together either by brass links or short straight pieces of thick copper wire.

The test box is divided into two portions, firstly, the line part dealing with the lines and up and down instrument

terminals, and, secondly, the battery portion, the latter being subdivided at large offices into main and local battery panels.

Each circuit requires four terminals, viz. line, up instrument, down instrument, and earth. The latter terminal is made common to two sets, and therefore each pair of circuits requires 7 terminals. Generally the up lines are placed at the top and the down lines at the bottom, but, in

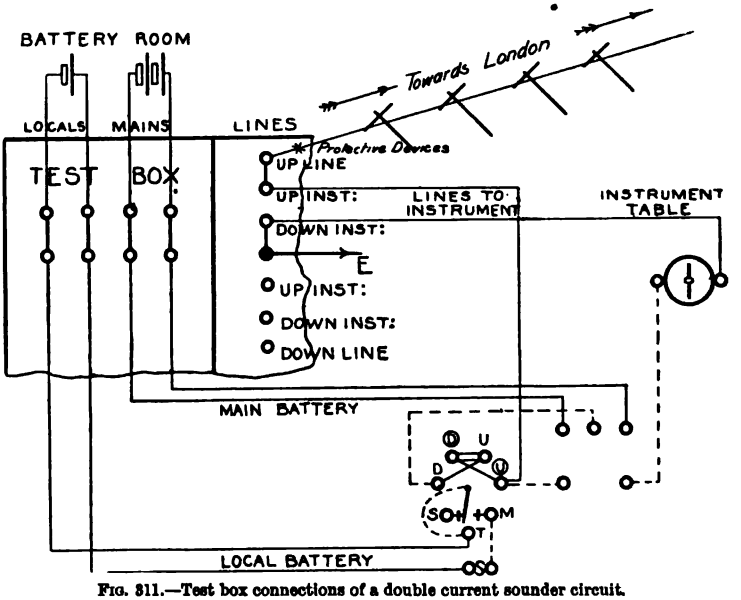


FIG. 311.—Test box connections of a double current sounder circuit.

large offices, this arrangement is sometimes modified in order to economize space. A diagram of a test box with various changes in the circuits, etc., is shown in Fig. 312. Two terminal circuits are shown at a and a_1, the former being an up and the latter a down line.

Upon the line or terminal circuit panel of the test box the terminals are arranged in vertical rows of seven. The central row is of blackened brass and connected to earth, whilst the topmost and bottom terminals are respectively reserved for up and down lines. The remaining terminals

serve for the up and down instrument terminals, and each vertical row of 7 terminals therefore accommodates one up and one down circuit.

The batteries pass through the test box in somewhat similar fashion, save that each battery requires four terminals.

The connections of one end of a double current sounder circuit are shown in full in Fig. 311. The line, shown as going in the direction of London, is an "up" line, and is therefore connected to the topmost terminal whilst the apparatus is consequently joined up as a down station.

The up and down instrument terminals are respectively connected to *U*-circle of the relay and to the galvanometer

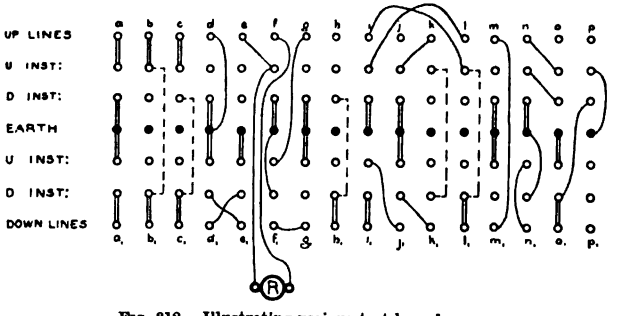


FIG. 312.—Illustrating various test box changes.

by two leads from the test box to the tables. Two brass links respectively connect together the up line and the up instrument terminals and earth and the down instrument terminals.

The arrangement of the batteries is sufficiently obvious, but it may be noted that *Z* is always upon the left and *C* upon the right-hand terminal of the pair.

The arrangement of the circuits upon a large test box is a matter of considerable importance. In such a case the terminated and through circuits cannot conveniently be divided into separate panels, largely on account of the increased difficulty which would be experienced in tracing "contacts." The wires are therefore arranged in the order of the routes which they follow, and above the wires forming any particular route a label is placed giving its name.

For instance, a route of twelve wires going to "*B*" *viâ* the "*Y*" canal would be labelled "*B viâ Y* canal" to distinguish them from a route which may go to "*B*" *viâ* a road line. The latter would perhaps be labelled "*B* road." The actual names is a matter for purely local consideration, but the principle is sufficiently apparent. The arrangement of the circuits in route order also facilitates the rapid location of the position of any particular wire—a matter of no small moment where the number of circuits is large.

Arrangement of Circuits and Test Box Changes.

In the subsequent headed paragraphs the various changes which may be made at the test box are explained in detail in reference to Fig. 312.

Terminal circuits.—This term is applied to all circuits upon which the office in question is either the up or the down station. Examples of the normal connections of two such circuits are shown at a and a_1. The former is an up and the latter a down line, from which it will be obvious that the a instrument must be joined up as a down and the a_1 instrument as an up station. Reference to the figure shows that these conditions are fulfilled when the links are placed as shown.

Intermediate circuits.—In these cases the office under consideration is the intermediate station. An example is given at c and c_1, the former being the up and the latter the down side of the circuit. The down instrument terminal upon the up side is connected to the down instrument terminal upon the down side by means of a connection at the back of the box. The two links join up the set in the correct direction, *i.e.* up and down instrument terminals to the up and down lines respectively. This enables the up line and the down line to be placed with the wires following the same routes, but even if this was not essential the same number of terminals would still have to be employed.

Through circuits.—This term designates wires which pass through the test box for testing purposes only. For example, *LV—NT* passes through the test box at Manchester, and is there called a "through wire." An example of the way in which such a wire is joined up at a large office is

shown at b and b_1. The up or Liverpool side is joined to b and the first instrument terminal is connected (behind the box) to the down instrument terminal at b_1, to which the down or Newcastle side of the wire is linked. In small offices the down side would be connected to the first instrument terminal or the circuit would be connected to the through panel. This course is utterly unsuited to the needs of a large office for reasons already stated (page 553).

To earth a wire.—This expression means to connect the wire named to earth, and an example is given at d. The up line link is removed and the connection made by a length of thin gutta-percha-covered wire as indicated.

To disconnect a wire.—This is accomplished by the removal of the link as shown at h.

To loop two wires.—The two lines f_1 and g_1 are joined together, or, to use the more usual expression, are looped. A request to loop several wires means to bunch them together, unless the request specifically states that they are to be looped in some particular way.

To reverse.—This term signifies the reversal of the up and down line terminals of the set. In the case of special arrangements it is often necessary to request an office to work as a down instead of an up station, or *vice versa*. The instrument at n_1 is normally joined to n_1 as an up station, and the connections shown are required in order to reverse the set.

Metallic circuit.—This term is used to designate a circuit in which the earth return is substituted by a second wire between the two stations. The circuit is said to be metallic because it wholly consists of metal, without the use of earth. Such circuits are frequently formed during the prevalence of earth currents, but this course cannot be followed where universal batteries are used (*vide* page 630). An example is given at i_1 and j_1 where the up instrument terminal of the i_1 set is connected to line j_1 instead of to earth. A similar connection is of course made at the distant station.

To divide a wire.—This expression signifies the termination of a through wire upon two sets of instruments. The through wire shown at k and k_1 is terminated upon the instruments normally used to work the circuits connected to j and j_1. Had it been desired to come in as an inter-

mediate station with the set normally used for the j_1 circuit, it would only have been necessary to remove the links at k_1 and between the up instrument and earth terminals at j_1 and then to join k_1 as shown and the up instrument terminal at j_1 to k_1 down instrument terminal. The link at k would have remained in its normal position.

To fork wires.—The two lines at e and f are shown forked to the f instrument, a rheostat being included in the f line in order to raise its resistance so that the current sent out shall divide equally between the offices connected to e and f. In this case the signals sent out from the f instrument will be correctly received by both e and f, and their signals will also be correctly received upon the f instrument, but the signals sent by e would be received reversed at f, and f's signals would be reversed at e. In the majority of cases this is immaterial, since the arrangement is usually made for the signalling of press messages *to* the forked offices. Where it is essential that the forked offices should be able to communicate with each other a forked repeater is required.

In the example shown both the forked circuits are up lines, but had one of them been down whilst the other was up one of the offices would have had to be requested to reverse their instrument (*vide* n_1).

To join through.—The two lines at m and m_1 are joined through. In this case these two terminal circuits are given up to form a through circuit. For example, a Manchester-London circuit might be joined through to a Manchester-Newcastle circuit in order to form an additional Newcastle-London circuit during a time of pressure.

To tap a circuit.—This expression signifies the introduction of a second set of apparatus at either of the terminal offices. This may be accomplished as shown at n and o, where the o instrument is placed in series with n. It may also be done in the manner shown at o_1 and p, where the p instrument is shown forked or in leak with o_1, but in this case the marks will be received reversed from *one* of the stations. It is advisable to introduce resistance with the leak instrument unless the circuit is a very short local one.

To cross instruments or circuits.—The term denotes the substitution of the first instrument or line for the second

instrument or line and the substitution of the second for the first. For example, it might be required to work Wheatstone upon a circuit ordinarily worked by key. A Wheatstone circuit which is being worked by key and upon which the automatic apparatus is not for the time being required is substituted for the key-worked apparatus and the latter is joined up to the Wheatstone line. Such a change is shown at d_1 and e_1, but it should be remembered that the battery power may need alteration.

It is frequently necessary to cross wires in the same way. If the cross shown at d_1 and e_1 were made at the distant end of the circuits or at some intermediate point, the d_1 instrument would then be working to d_1 and e_1 instrument to e_1, but with lengths e_1 and d_1 lines inserted in place of the lengths or a part of d_1 and e_1 respectively.

If a long circuit is working badly owing to a defective length of line it is frequently possible to substitute a perfect length from a shorter circuit and replace the latter by the defective length. In many cases this substitution does not seriously affect the shorter circuit. Again, it may be possible to give up the shorter circuit altogether or, perhaps, one good circuit may be made from two defective ones. This subject is, however, fully dealt with in Chapter XIX, and the foregoing explanation will probably suffice for the purposes of the present subject. An example of a cross between a through and a terminal circuit is shown at *i* and *l*.

In crossing instruments it is essential that care should be taken to join up the apparatus correctly at the test box. The principle and reason for this is sufficiently dealt with in Chapter V. An example is given on the diagram where in using the apparatus at f_1 (normally joined up as an up office) to work the *g* line (an up line) the up line terminal of the instrument is joined to *g* and the down terminal is earthed.

Test Box for Small Offices.

The form of test box, which is still in use or is being fitted at offices of comparatively small size, is illustrated in Fig. 313. It will be observed that a separate panel is provided for "through" circuits, since it is only necessary

to preserve the route order of the wires when the number is very large. For the same reason, only two terminals are required for each through circuit. Main and local batteries are grouped together upon the end panel, a set of four terminals being required for each battery.

The number of terminal circuit, through circuit, and battery, panels is arranged to suit the requirements. The box is constructed of teak, and each panel is hinged upon

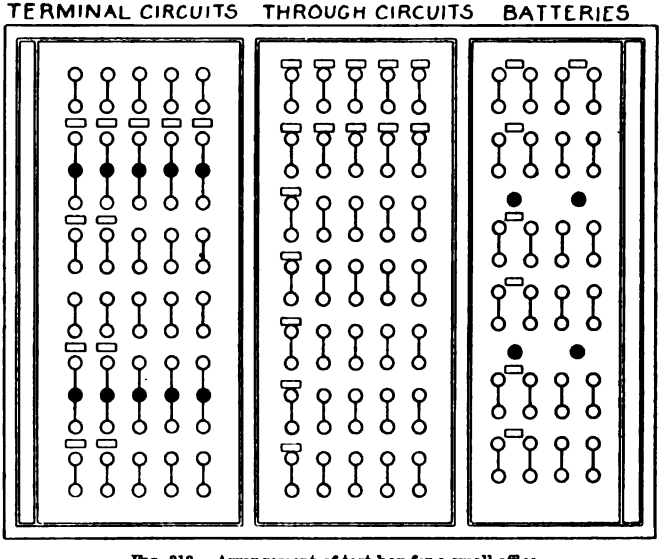


FIG. 313.—Arrangement of test box for a small office.

the left in order to afford access to the wires at the back. The dimensions of the box shown in Fig. 313 is 2′ 8″ high by 3′ 4″ wide. It is fixed at a suitable height upon the wall of the instrument room and the wires led to it by a casing.

The terminals are made with a stout pin which projects behind the box and to which the wires are soldered. It is essential that resin shall be used as the flux when soldering owing to the corrosive effect of the various soldering fluids.

Battery Test Box.

The battery test box or panel should need little comment, in fact a comparison of Figs. 311 and 313 should make the arrangement sufficiently obvious.

To increase the power.—Remove the link connecting *C* of the battery to the instrument and join the former to the *Z* of the battery to be added. The *C* terminal of this battery is then connected to the *C* instrument terminal.

To cross two batteries.—All four links are removed and then *Z* and *C* of the first battery are respectively connected to the *Z* and *C* instrument terminals of the second set of

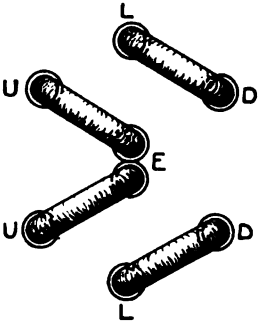


Fig. 314.—U-link test box line and instrument connections.

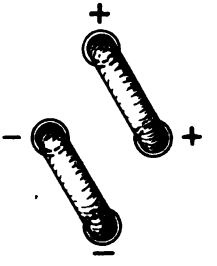


Fig. 315.—U-link test box battery connections.

apparatus. Similarly *Z* and *C* of the second battery are respectively joined to *Z* and *C* of the first instrument.

U-link Type of Test Box.

The U-link type of test box was introduced shortly after the transfer of the telephone trunks to the State. The four test holes needed for each line circuit are arranged in diamond fashion as shown in Fig. 314. The upper and lower test holes of the upper set are joined to line and earth respectively, whilst the left and right holes are connected to the up and down instrument terminals. The figure shows two down lines connected to two instruments correctly linked to them. To reverse an instrument it is

merely necessary to reverse the positions of the links, the distances between *L* and *U*, *L* and *D*, *L* and *E*, *E* and *U* and *E* and *D* being equal. To earth a line, one link is removed and the other placed between *L* and *E*.

The battery test holes are as shown in Fig. 315, the upper and lower holes being connected to the battery. The distance between these holes precludes the possibility of short-circuiting the battery by wrongly placing a U-link between them.

Switch Spring Type of Test Board.

The great advantage of the new switch spring test board is its compactness and the fact that the only connections upon the face of the board are those employed to make crosses or other abnormal arrangements. This form of test board is, however, only used at offices where secondary cell working is in vogue.

With the exception of sets of apparatus which are or may be employed for intermediate working, the earth connection of every instrument is made at the instrument table and not at the test board as in the old test box. The advantages gained are the saving in wire and the reduction in the size of the test board consequent upon the reduction in the number of switch springs required. Since a suitable number of instruments are fitted for intermediate working and provided with a reversing switch no difficulty is experienced upon account of the inability to reverse. In a case of special and urgent need the relay connections could be reversed at the table and the battery connections altered at the distribution case (by means of test pegs).

Each panel of the test board accommodates 120 circuits and also provides for the requisite number of transfer circuits, earthing, grouping, morning test looping, and intermediate return, switch springs.

A sketch of the general arrangement of a two-panel test board is given in Fig. 316. It accommodates 240 circuits and has a total width of but 4′ 9″.

The 120 lines are brought to each panel of the test board in a 127-wire lead-covered cable, the odd seven wires being provided as spares. The conductors are 40 lb. copper wires insulated with silk and cotton, the whole being covered with a seamless sheathing of lead.

Upon the vertical board behind the front apron are placed twenty-four 20-tag cross-connection strips. Each

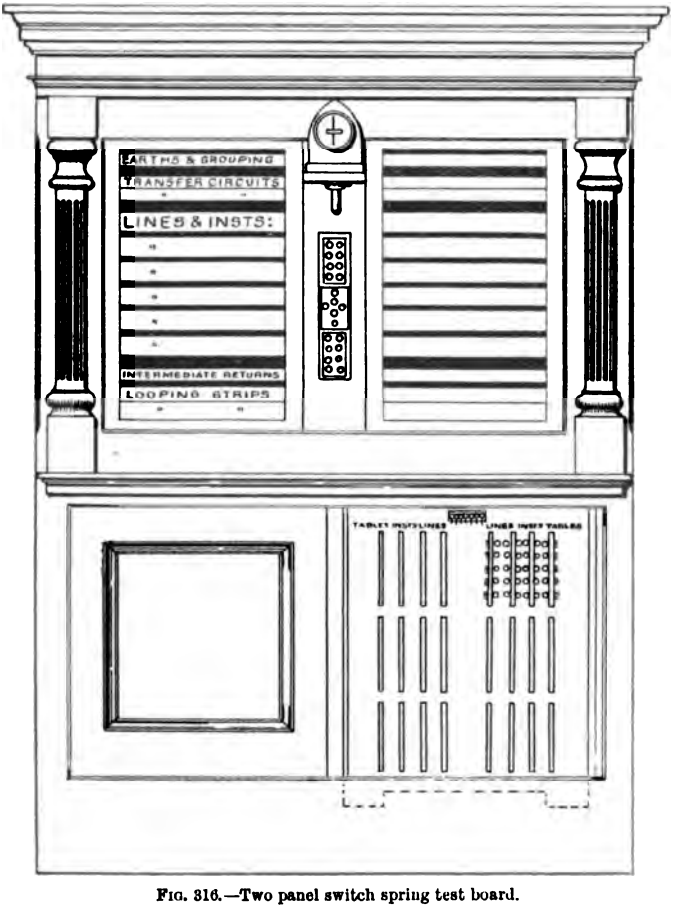


FIG. 316.—Two panel switch spring test board.

strip consists of a square rod of ebonite with twenty tinned brass stampings placed within the slots prepared for their reception and held in place by thin strips of ebonite screwed down upon them. The brass stampings project

upon either side of the ebonite and bear a small hole at each end through which the two wires to be connected are passed and soldered upon the top.

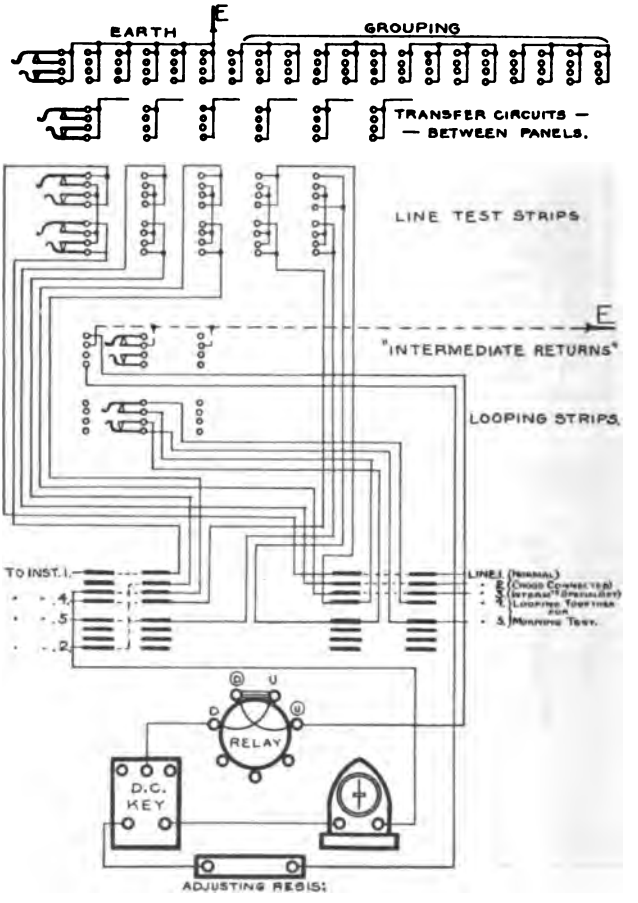


FIG. 317.—Principle of switch spring test board.

PRINCIPLE.

The principle and connections of the apparatus and lines to the switch springs will be apparent from a consideration

of Fig. 317. No. 1 line is joined to the right-hand side of the line tag, which is connected through to the opposite tag by means of a bare piece of tinned copper soldered between them. The line then passes on to the upper or line switch spring, where it is connected to both long and short springs. The inner springs of the line switch spring are joined to the inner springs of the instrument switch spring, and the latter's outer springs are joined to the right side of the instrument tag. It is there connected to the left of the tag by a bare wire, and the left end of this tag is joined to the lead to the instrument table. By placing the springs in parallel in the manner indicated the risk of a disconnection is greatly minimized.

Cross-Connecting Facilities.

In each circuit there are two points bridged by short lengths of bare wire, and by removing them crosses and changes may be made without disturbing the line cable, cables to the instrument tables, or the connections between the switch springs and the tags. To change the permanent positions of two instruments of similar type it is only necessary to remove the bare wire connections between the instrument and table cross-connections and to make the cross with covered wire. Again, lines may be crossed between the two line cross-connection strips. The wires used to form these cross-connections are taken behind the board, where suitable brass supports are provided for their reception. It will therefore be realized that crosses and changes of every description may be made without interfering with any connections other than those between the two pairs of cross-connection strips. The importance of this provision in a large office will be obvious and its value can scarcely be over-estimated.

Line No. 2, which was originally joined to the apparatus connected to the second instrument tag, is shown cross-connected on to the apparatus in connection with the eighth tag. Without cross-connecting facilities it will be obvious that the lead from the table would have had to be manipulated and probably lengthened. In the course of a few years, or less if the changes were frequent, the cables to the instrument tables would be scattered all over the

box in what would appear like hopeless confusion, and scarcely one of the wires would be without joints.

Test Box Changes and Transfer Circuits.

For making crosses or for connecting the testing or other apparatus to the various lines and instruments pairs of pegs and cords are provided. The pegs are of brass, but are provided with fibre covers. When a peg is inserted into a switch spring the outer springs are forced apart and break connection with their inner springs. If the second peg of the pair is then thrust into a second switch spring its outer springs are connected together through the cord to the outer springs of the first switch spring. As there are two switch springs for each terminal circuit, two lines and instruments may be crossed by using two pairs of pegs and cords.

The top strip of 20 switch springs is used for earthing and grouping lines or instruments. The first six switch springs are earthed, and thus any line may be earthed by pegging it to one of these switch springs. Two sets of respectively 3 and 4 switch springs are connected as indicated for grouping wires together. For example, if it was required to fork No. 1 instrument to lines 2, 3, and 4, it would be necessary to plug No. 1 instrument, No. 2 line, No. 3 line, and No. 4 line on to the first, second, third and fourth switch springs of one of the groups.

In order to avoid the use of exceptionally long cords to reach from one end to the other of a large test box, a certain number of transfer circuits is provided. Each panel has 20 switch springs for this purpose, and these are connected in such a way as to provide a sufficient number of circuits to each panel of the board. A connection between two switch springs at opposite ends of the board is effected by means of two pairs of ordinary cords, one end of each pair being placed in the switch spring at either end connected to the transfer circuit used.

Special Intermediate Sets.

Line No. 3 is shown connected to an instrument fitted for intermediate working. In order to confine the attention

to the principles involved the detailed apparatus connections have not been sketched. The line normally connected to the set passes through the line and instrument switch springs to the galvanometer in the ordinary way, but *U*-circle of the relay and the end of the adjusting resistance are taken to a special switch spring upon the "intermediate returns" strip. Under normal conditions *U*-circle of the relay is earthed through the inner spring whilst the adjusting resistance lead is disconnected. It will therefore be seen that No. 3 instrument normally works as a terminal station. When it is required, for special work, as an intermediate set, the longer line is connected to the instrument and the shorter one to the intermediate return switch spring, the changes being made by two pairs of pegs and cords. By inserting one peg in the long line to be used and the other in the instrument switch spring, the long line's instrument is disconnected from the long line, the line normally connected to the intermediate apparatus is disconnected, and the long line joined to the galvanometer of the intermediate set. The short line is plugged through to the intermediate return switch spring which disconnects earth from *U*-circle and, since the plug is solid, connects *U*-circle and the adjusting resistance to the short line. The full connections of the apparatus were given in Fig. 287, which may now profitably be considered in relation to the foregoing paragraph.

Looping Strip.

Lines No. 4 and 5 are also shown passing through a switch spring upon the looping strip. No. 4 line passes through the long spring and its inner spring back to the left-hand line tag, and so on to its line and instrument switch springs. No. 5 line similarly passes through the short and its inner spring. When an unconnected peg is inserted in the looping switch spring, lines 4 and 5 are looped through the peg. This provides a simple means of looping all those circuits which have to be looped each morning for testing purposes. In some cases the number is very considerable, and the tangle of cords upon the front of the box which would otherwise result is entirely avoided. Moreover, the circuits may be arranged upon the looping

strip in the order of the times at which they are to be looped.

A test-hole tablet and a differential galvanometer, fixed upon a turntable, are mounted upon the vertical rail between the two panels. These testing arrangements will, however, receive further consideration in Chapter XX.

PART II. LIGHTNING PROTECTORS.

Theory of Lightning Protectors.

In the event of lightning striking a telegraph wire, serious damage to the apparatus employed would result if steps were not taken to provide against its passage through the instruments. Every set of apparatus is provided with a lightning protector, which consists essentially of a small spark gap between line and earth. Before describing any of the forms given to the apparatus in practice, it is essential that the theory of its action should be clearly comprehended.

A lightning discharge differs from an ordinary telegraphic current in two particulars, viz. its potential and the suddenness with which it occurs. A spark is produced when the electric strain upon the dielectric (air) reaches such a value that the air breaks down. The potential of a telegraphic current is very seldom more than about 200 volts, and this is insufficient to cause a spark of even the most minute dimensions. The currents are also comparatively slow in their occurrence, *i. e.* slow in comparison with lightning. Protection which would amply suffice for slow, heavy currents would be quite useless in the case of lightning. In order to make the distinction clear, the following analogies relating to mechanical inertia may prove of value. Let a quantity of gun-cotton be placed upon a slab of stone in the open air. Ignited with a match, nothing beyond a "fizz" will take place, but if fired with enormous rapidity by means of a detonator, the stone will be blown to fragments. The explanation is that, in the second case, the air above the gun-cotton, possessing inertia, will not move instantaneously with sufficient

rapidity. The inertia resistance of the air is in this case clearly enormous, and it finds a parallel in the inertia resistance of the electromagnet to a lightning discharge. Yet another example of a similar phenomenon is the fact that a loose plug of snow in the end of a rifle is sufficient to cause it to burst when fired.

It has previously been pointed out that an electromagnet possesses a considerable self-inductance, and that the effect of this is to delay the rise of the current through it. The magnetic field, which is produced by a current, in springing into existence, cuts through the windings, and therefore generates an opposing E.M.F. termed the back E.M.F. of self-induction. This effect may correctly be regarded as electro-magnetic "inertia resistance." The resistance which would give an equivalent current when the E.M.F. in question was steadily applied to it is termed the "impedance." This quantity depends upon the rate at which the current rises, and means an equivalent resistance to that which would produce the value of current given by Ohm's law.

The equivalent resistance or impedance offered by the apparatus to a lightning discharge is enormous, and as the discharge is of sufficiently high potential, it breaks down the insulation of the air, and escapes to earth by the path of lesser resistance.

Reel Protector.

One of the earliest forms, known as the "reel protector," consists of a single layer of fine silk-covered copper wire wound upon a brass tube connected to earth. The working currents pass through the insulated wire, whilst lightning discharges pass from the wire to the earth-connected tube. This device is still in use upon submarine cable circuits, but only as an auxiliary.

"A" and "B" Protectors.

The "A" form of protector (Fig. 318) consists of two circular brass plates, separated by a mica disc bearing three radial holes. The binding screw, which clamps the plates together, is furnished with an insulating bush of ebonite, so shaped as to prevent the screw from making

contact with the upper plate. The line wire is placed between the plate and the projecting collar of the bush, so that it may make contact with the top plate whilst being insulated from the screw. The lower plate is connected to a separate terminal, which is earthed. The plates are tinned upon their inner faces, and the remaining parts lacquered.

FIG. 318.—"A" form of lightning protector.

At intermediate offices the "B" protector, which consists of three plates, separated by two similar mica discs, is still in extensive use. The central plate is earthed, whilst the

FIG. 319.—"C" type of lightning protector.

upper and lower ones are respectively connected to the up and down lines.

The protector shown upon the right of Fig. 318 consists of two "A" protectors, placed side by side, and is used for protecting two separate circuits.

"C" PROTECTOR.

The "C" protector, two of which are shown mounted upon one base in Fig. 319, is similar to the "A" form, but with carbon plates of somewhat smaller diameter substituted

for the brass. The lower carbon plate is mounted upon a tinned brass holder, which is fitted with a screw for attachment to the terminal block. The other plate is held in position by means of a clamping spring screwed down to an earth-connected brass bar. In order to greatly increase the length of the surface, over which a leakage current would have to travel on its way from plate to plate, the triple mica disc was designed. It consists of three discs placed one over the other and cemented together. The two outer discs have a central hole of larger diameter than that of the middle disc, consequently the portion projecting beyond the upper and lower discs is not in contact with the carbon plates. Some difficulty was, however, experienced owing to carbon dust, abraded from the edge of the central hole in the plate by the clamping screw, falling between the plates and so establishing a connection between them. It has, however, been overcome by reverting to the use of a mica disc with three radial holes, but with these holes recessed from the solid mica. In this way the length of the leakage surface intervening between the plates has been made equal to that of the triple form, whilst obviating the difficulty referred to.

The latest type of "C" protector is mounted upon a stabilit base, and is furnished with a sheet-iron cover so as to avoid all risks due to fire caused by lightning discharges. Where from one to six lines are to be protected, the "C" form is employed, but above this number the smaller and more compact "D" type is used.

"D" Protector.

The "D" protector, to be seen in Figs. 327, 332, and 333, consists of two oblong plates of carbon, about one inch long and half an inch wide, separated by a mica plate of similar size, but with a rectangular portion cut away at one side to provide an air gap from plate to plate. The latest form of mica is oblong and bears three small circular holes. The lower blocks rest upon a tinned brass earth plate, whilst the upper plates are held on to the mica discs and lower plates by the springs which form the line connections. In some cases the upper plate has a small hole filled with metal which will fuse, and so put the two plates

into contact when a discharge takes place. This secures the apparatus against damage, and also blows the fuse placed in the direct circuit (*vide* page 579).

Vacuum Protector.

The vacuum protector is most efficient, but suffers from two defects. It is entirely destroyed when a discharge has passed through it, and it requires periodical testing to determine its efficiency. It consists (Fig. 320) of a hermetically-sealed glass tube from which nearly all the air has been exhausted containing two electrodes separated by a short gap. The creation of a low vacuum renders the difference of potential necessary to break down the medium between the points far less than would be necessary in an ordinary atmosphere. The protector is therefore far more efficient than any of the types previously described, but as this efficiency depends upon its vacuum being maintained, a monthly test of its condition is necessary. In order to effect this, a small induction coil is connected to the protector and a violet glow will be seen to fill the tube if it is in perfect order.

Fig. 320.—Vacuum lightning protector.

The vacuum protector is employed chiefly upon cable and underground circuits to which an open line is, or may be, connected. The "C" protector is frequently used in the pole test boxes at the junctions of open and underground lines, but it is not entirely satisfactory on account of the reduction of its insulation which occurs when there is the least dampness.

Tablet Protector.

The "tablet protector" is used upon all Post Office submarine cable circuits at the junctions of the cables and the open or underground lines. The device practically comprises a plate protector, a fuse, an inductive coil and a reel protector. The fuse is of the ordinary glass tube type, and is supplemented by a coil of fine platinum silver wire wound upon a metallic bobbin connected to earth. This coil (Fig. 321) acts as a reel protector, but an even more important function is to provide an inductive resistance

immediately before the cable. The plate protector itself consists of two large oblong brass plates separated by a large mica disc with suitable holes to provide air gaps. The land line is connected to the fuse and the cable to

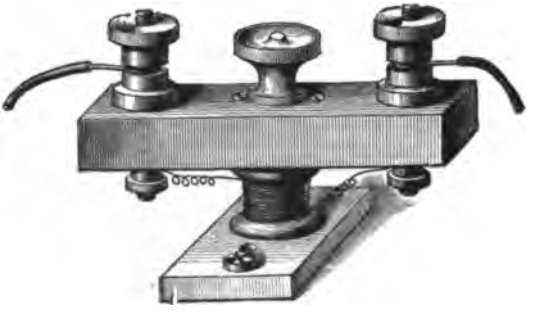


FIG. 321.—Bobbin of "tablet" protector.

one end of the bobbin, whilst the junction of the fuse and bobbin is teed to the protector.

The arrangement is a most efficient one, but is, of course, more costly than any other types described.

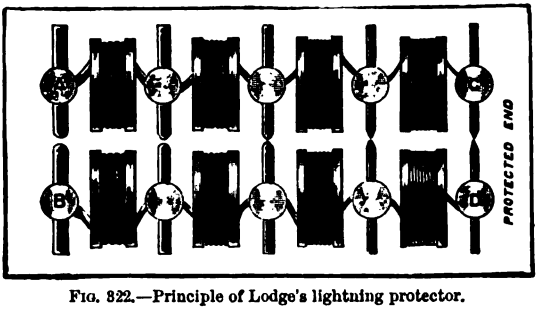


FIG. 322.—Principle of Lodge's lightning protector.

PROTECTORS OF SAUNDERS AND LODGE.

By way of conclusion to the descriptions of lightning protectors it will be interesting to consider two other types, viz. those of Saunders and Lodge. The former is in use upon many submarine cable circuits and consists of about 18 inches of fine platinum wire, kept stretched by a spring,

along the axis of an earthed copper tube. The effect of a lightning discharge is to fuse the wire and so to break the circuit.

A view and the actual connections of one of Lodge's protectors are shown in Figs. 322 and 323. The instrument to be protected is connected between *C* and *D*, whilst the line and earth are joined to *A* and *B*. Each coil of

FIG. 323.—View of Lodge's lightning protector.

wire is wound upon a groove in the ebonite pillars and the spark gaps are made by approaching stout brass rods. When a heavy lightning discharge enters by the line, the major portion passes across the first gap while the remaining portions are filtered through the other gaps. The self-induction of the coils plays a vitally important part in choking back the discharge. Since the coils are wound upon a non-metallic pillar, there is no possibility of the lightning discharge escaping other than through the air gaps; moreover for such discharges the

impedance of coils so wound is far higher than with an iron core. The two final gaps are provided with screw adjustments so that the distance may be reduced to a minimum.*

In another form the Lodge and Saunders protectors are combined, and this appears, from a theoretical point of view, to be an ideal combination. The Lodge device absolutely secures against high potential, while the Saunders device ensures that the current shall not rise to danger-point.

Position of Protector and Formation of an Inductance Spiral.

The latest practice is to place the protectors as near as possible to the point at which the wires enter the telegraph office. The earth connection from the protectors when there are more than six is made with a seven-eighteens, and when there are six or less with three-eighteens, bare stranded copper conductor, and the route followed by it on its way to earth is made as short and straight as possible, all sharp turns and bends being avoided to the uttermost extent. The wire should also be kept away from gas-pipes, and more especially when of lead, in order that the risk of "side-flashing" may be minimized. It will be obvious that a lightning discharge jumping from the earth wire to a leaden gas-pipe might readily produce a serious conflagration. Under no circumstances should internal gas-pipes be near or be connected to the earth wire, and a connection between the service pipe on the street side is usually inadvisable. The street water-mains provide an excellent earth connection and are frequently used for this purpose (see page 164).

The lead from outside is first taken straight to the protector and a spiral of about 10 turns of wire with a diameter of about $\frac{1}{4}$ to $\frac{3}{8}$ of an inch is formed in the lead to the instrument at the point at which it leaves the protector. The behaviour of this spiral resembles that of the coils of the

* The full description of the experiments and tests which led to the design of the Lodge protector and the discussion upon the merits of the various forms is to be found in the *Journal of the Institution of Electrical Engineers*, vol. xix, page 346 *et seq.*: "On Lightning Guards for Telegraph Purposes," by O. J. Lodge.

Lodge protector, and since a spark of one millimetre length means that the E.M.F. acting is 3000 volts, the importance of efficient protection can hardly be over-estimated. It has been pointed out how great a resistance a relay or other telegraph instrument offers to a lightning discharge, but the statement needs to be qualified, since such a discharge jumps across the winding, and so avoids the self-induction. The small inductive spiral offers a very high resistance to an impulsive discharge, and there is no doubt that the addition is of the utmost importance in increasing the efficiency of the protection afforded.

The iron cases of the protectors should be earth-connected, so that lightning discharges side-flashing to them may be safely carried away. Similar remarks apply to the iron-work of test and cross-connection frames, and to the cable connection boxes described later, and, indeed, to iron troughings and the sheaths of lead cables.

It may perhaps be remarked that the connection of the line wire to the protector by joining the line to the instrument and then continuing it onwards to the protector is little better than omitting the protector entirely. If, in addition, the line wire is coiled spirally where it is connected to the protector, the inefficiency of the arrangement can scarcely be increased!

PART III. PROTECTION FROM POWER CIRCUITS.

With the advent of electric tramways, worked from overhead conductors, there arose the necessity, firstly, for reducing the possibility of contacts between telegraph and telephone and power wires to a minimum; and secondly, to guard against damage to the apparatus and to avoid the risk of fire should such a contact occur. The first condition has been met by the provision of "guard wires" above the power circuits, and the second by the use of fuses and "heat coils" upon the telephone and telegraph circuits within the area in which the trams are in use.

Guard Wires.

Where there is a single trolley wire, above which a route of telegraph wires cross it, two wires, usually of No. 8

galvanized iron or seven strands of No. 16 wire, are erected at least 24 inches above the trolley wire. The two guard wires overlap the centre of the trolley wire by 8 inches upon either side, and both are efficiently earthed by connecting them *viâ* the support to earth by means of a copper wire.

The ideal arrangement consists in connecting the poles to the rails with copper bonds in just the same way that the various lengths of rail are bonded together to form the return conductor for the tramway currents. Where the guard wires exceed 200 yards in length, at least one earth connection per 200 yards should be made to the wires. The supports for the guard wires should be rigid, and at every support each guard wire should be securely bound in, or terminated.

The number of guard wires erected is in accordance with the gauge of the wires crossing, and the number of, and distances between, the parallel trolley wires. For instance, each trolley wire requires two guard wires when the distance between them is over four feet, whilst for a distance of from 16 to 48 inches three guard wires are used.*

The guard wires serve to prevent a broken telegraph line from falling directly on to the trolley wire. Where the wire happens to curl over and so to make contact with the trolley wire, it is also in contact with the earthed guard wire. Usually the current flowing to earth through the wire which forms the contact is sufficient to burn it up, or, with heavy gauge wires, is sufficient to blow the tramway section fuse. Another serious danger which the guard wires obviate is that a fallen telegraph wire in contact with the trolley wire would, of course, give electric shocks to any one who, without the aid of india-rubber gloves, was unwise enough to touch it. It may be said that efficiently maintained guard wires very greatly reduce the risks due to falling telegraph wires, but it must not be overlooked that the breakage of telegraph wires is a comparatively rare occurrence, especially when the wires are terminated upon either side of the crossing.

* The full text of these regulations is given in the *Electrician* of February 20, 1903.

Use of India-rubber Gloves.

Whilst men are working upon wires in the vicinity of a point at which they cross the trolley wires, india-rubber gloves are invariably employed to guard against shocks. There is not only the danger of the shock itself, which is seldom fatal, but the risk that the man may be startled, and so fall from the pole. This could not, however, occur if the man was wearing a leather "safety belt."

Protection applied to Telegraph and Telephone Circuits.

Having described the guard wire arrangements which are applied to the power circuits, it is now necessary to consider the protective devices added to the telegraph and

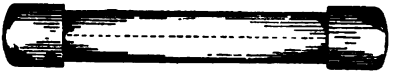


Fig. 324.—Glass tube fuse.

telephone circuits within the affected area. Supposing that a contact between a power circuit and a telegraph wire occurs, the effect of these devices is (1) to protect the apparatus from damage, and (2) to prevent lines passing through the affected area from continued contact with the power wires. The first condition is fulfilled by the provision of a heat coil upon the line side of the apparatus, and the second by the use of fuses.

Glass-tube Fuse.

The glass-tube fuses (Fig. 324) employed consist of a thin platinum wire 5 mils in diameter, contained within a glass tube two inches long. The ends of this tube are closed by two tinned brass caps cemented with shellac. The fuse wire is passed through two central holes in the caps and soldered, the function of the other holes being merely to allow for the expansion of the air which results when the fuse is "blown." The brass caps form the terminal connections, and, as will be seen later, suitable clips are provided for holding and connecting the fuse.

Heat Coils.

It is impracticable, owing to the exceptionally small gauge of wire needed, to provide a fuse which will be blown by a current much less than one ampere. Now, a current of far less than this amount, flowing through a relay or other telegraph instrument, would produce very serious damage, and it is quite possible that a fire might even be originated in this way. The heat generated by a current in a conductor or system of conductors is proportional to the square of the current, to the resistance of the conductors, and to the time during which the current is flowing. The temperature of the conductors depends upon difference between the rate at which heat is generated by the

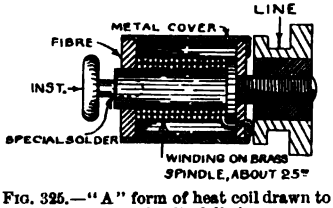


Fig. 325.—"A" form of heat coil drawn to about twice its full size.

Fig. 326.—Heat coil (full size).

current, and the rate at which the heat is radiated. When the conductors are in a comparatively confined space, the temperature may rise sufficiently to produce disastrous results.

The "A" type of heat coil "strikes" when a current of 250 m.a. flows through it for a period of 30 seconds. Currents smaller than 250 m.a. may pass for an indefinite time, whilst a larger current operates the coil more quickly. A section of a heat coil side by side with a view of its appearance are given in Figs. 325 and 326. A coil of fine wire is wound upon a small brass bobbin with fibre cheeks. One end of the coil is soldered to the bobbin, whilst the other end passes through to the grooved metal washer, which is carried by, but insulated from, the screwed extension of the bobbin. The left end of the bobbin is bored so as to receive the pin, which is secured in its position by a special type of solder having a very low

fusing point. When a current of 250 m.a. passes for 30 seconds the heat generated is sufficient to melt the solder, and the pin is then pulled out by the action of a spring and the circuit disconnected. The resistance of the coil is about 25ω. A recent improvement in design has been effected, and a heat coil which strikes at 250 m.a., but having a resistance of only 15ω, has been introduced. It may be distinguished from the 25ω coil by its blue-coloured case.

The heat coil already described strikes with 250 m.a. in 30 seconds, and it has been found that, upon high speed Wheatstone circuits of considerable capacity, these coils are operated by the working currents. In order to avoid this trouble heat coils with a striking point of 500 m.a. in

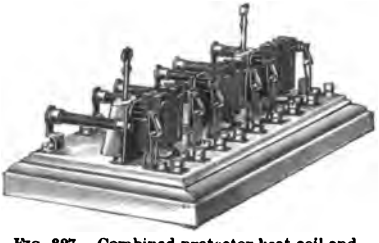


FIG. 327.—Combined protector heat coil and fuse fitting for six lines.

FIG. 328.—Metal cover.

30 seconds are employed upon such circuits. These two types of heat coil "A" are distinguished by the colour of the case, which is red for 500 m.a., and black or blue for 250 m.a. coils.

There is another form of heat coil, occasionally used upon test frames, which is known as the "B" type. It differs from the "A" form in that the heating of the fusible alloy causes the coil itself to slip down the projecting pin, upon which it is soldered, into the interior of the cover. The spring consequently presses the pin forward sufficiently to bring about the earthing of the line. The resistance of the coil is 30ω with a striking point of 250 m.a., and 3·8ω with a striking point of 500 m.a., the latter form being very extensively used in connection with the Common Battery telephone system.

COMBINED PROTECTOR, HEAT COIL AND FUSE FITTING.

Where the number of circuits to be protected is very small, such as at sub and other minor offices, the heat coil, protector, and fuse, are mounted together upon one base. Such a fitting, suitable for six lines, is shown in Fig. 327. The base is of porcelain and the cover (Fig. 328) of tin, lined upon the interior with fire-proof material. The protectors are of the "D" type and fuses of the glass-tube pattern, already described, are employed. The heads of the heat-coil pins are placed within the slots of the two brass springs which exert an outward pull upon the pins.

The general arrangement of a fuse, protector, and heat

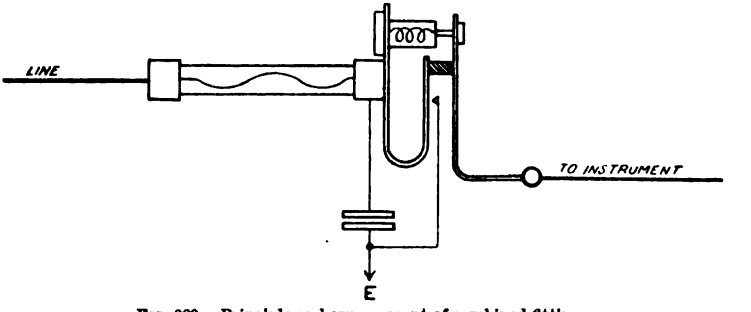


FIG. 329.—Principle and arrangement of combined fitting.

coil, is indicated in Fig. 329, from which it will be observed that the line wire is connected to the fuse, and that the protector is placed at the junction of the heat coil and the fuse. In the later forms of the apparatus a second spring, held away from an earthed contact point by the spring operating the heat coil, is added. A current of 250 m.a., whilst leaving the fuse intact, operates the heat coil, so disconnecting the instrument and earthing the right-hand side of the fuse. Usually, the reduction in the resistance of the circuit increases the current sufficiently to blow the fuse and disconnect the line.

The fuse is also of service in the case of lightning discharges, since the current passing through the fuse and protector to earth disconnects the circuit. In this way the risk of a fire originated by a series of large discharges

through the protectors is greatly minimized. As a matter of fact, fuses are the only means adopted to prevent lightning discharges from causing damage to the 7-pair distribution cables used in connection with the London telephone system.

Principles Governing the Fitting of Heat Coils and Fuses.

Where a route of through wires traverses a power area,

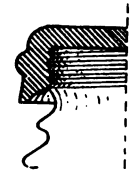


Fig. 331.—Section of fuse cover showing the screw.

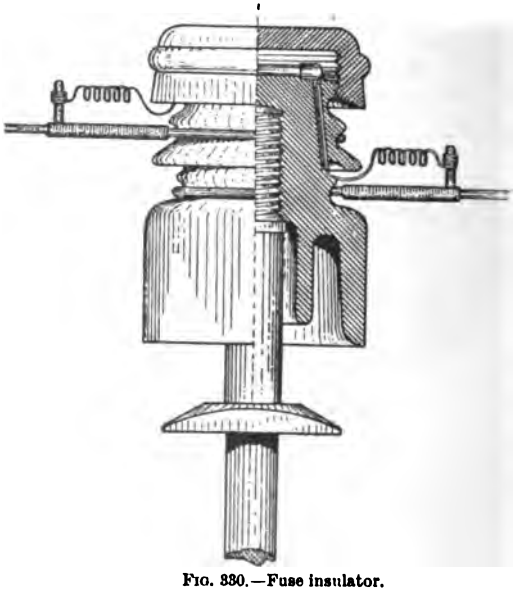


Fig. 330.—Fuse insulator.

fuses are inserted at the boundaries, whilst the offices upon each wire are protected by heat coils. These fuses are fixed upon specially designed fuse insulators (Figs. 330 and 331). The insulator is of the same general pattern as the P.O. terminal type, but with a porcelain cap to cover the top in which a suitable groove is left. The fuses are provided with wire extensions which are soldered to the two sides of the line wire terminated in the upper and lower grooves of the insulator. A later type has recently been introduced, having a black ambroin cover and fitted

with fuse clips, so as to facilitate the replacement of blown fuses by avoiding the necessity for soldering.

When a contact with a power wire occurs, the heat coil at the office is operated, and the earthing of the circuit blows the fuse at the boundary of the area, and so prevents the length of wire between that point and the office from remaining "live."

The positions of the fuses are governed by the following rules, which may readily be deduced from the general principles already stated.

(1) In the case of a single crossing a fuse is fixed at any convenient point upon either side of the crossing.

(2) In a power area one fuse is fixed at the office (or at the junction with the underground) and one just beyond the boundary of the area.

(3) A wire passing through an office within a power area requires a fuse at each boundary, and two, either at the office, or at the ends of the underground.

(4) Through wires passing through a power area without entering an office require one fuse at each boundary.

(5) In the case of "leak" circuits one fuse is inserted in each wire of the main circuit, or in default one fuse at each office.

(6) The distance between two fuses must not exceed 50 miles, nor must the resistance of the line connecting them exceed 100$^{\omega}$.

A few typical cases may be considered by way of illustration. Consider a head office with a number of sub-offices served by open wires, all of which are within an area where electric trams are running. Each sub-office would be protected by a 2-line combined heat coil protector and fuse fitting of the type shown in Fig. 327. At an intermediate office both sides of the fitting would be needed, whilst at a terminal office only one fuse, heat coil, and protector, is required. At the head office the fuses are placed in a separate weather-tight case at the base of the standard upon the roof, and the heat coil and protector fitting is fixed inside the building. The fitting of fuses within the building is undesirable, and, where the small combined fittings are used, they should be placed as near as possible to the point at which the wires enter.

Had the wires from the sub-offices entered the large office

through a length of underground the fuses would be placed in the pole test box at the junction of the open and underground lines.

Conditions 5 and 6 require the addition of a central fuse where the various electric tramway systems form a practically unbroken area of large dimensions. In such cases the

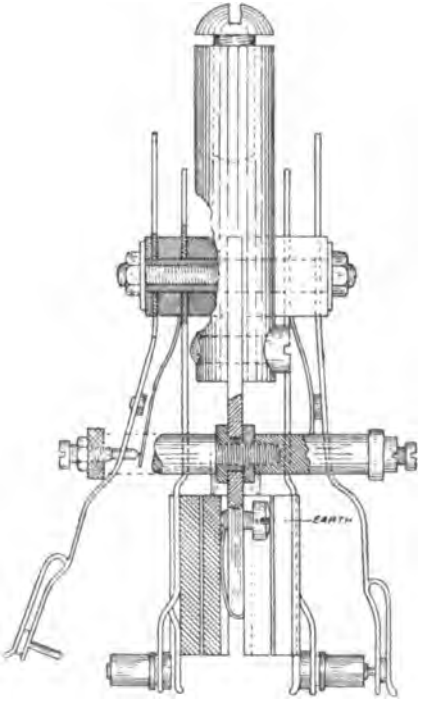


FIG. 382.—Heat coil and "D" protector strip.

100$^{\omega}$ limit for the resistance between the fuses makes it reasonably certain that the fuse will be operated when a contact with the trolley circuit (voltage usually about 500) takes place.

HEAT COIL AND PROTECTOR FITTINGS.

A view of a strip of heat coils and "D" protectors, together

with a section showing the precise arrangements of the various parts, is shown in Figs. 332 and 333. The strips are mounted in cast-iron boxes with iron covers, and are made in sizes to take 20, 40, 80 and 160 wires respectively. Cross-connection strips are also added, and these serve the same purpose as the cross-connection fields of the switch spring test box.

At offices of the largest size the heat coils and protectors are placed in a basement fire-proof chamber. The strips are fixed upon the test and cross-connection frame, but are of exactly the same general form as those shown in Figs. 332 and 333.

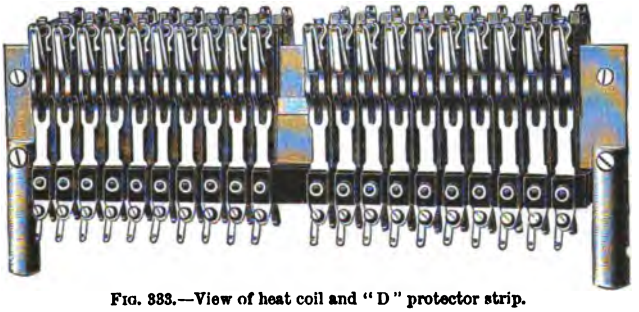


FIG. 333.—View of heat coil and "D" protector strip.

PRECAUTIONS AGAINST FIRE.

In this chapter perhaps it will not be out of place to call special attention to the fire precautions which now form a part of the standard practice of the Post Office. In the first place the materials used in constructing the building contain the minimum amount of wood, the floors being concreted and iron girders used where possible. It is true that, in this way, the building itself may be made fire-proof, but when the fittings brought into it are of a highly inflammable nature, immunity from fire at once ceases.

It will be obvious that the large casings passing from floor to floor partially filled with gutta-percha-covered wires, and the test box, which may consist of thousands of these wires more or less spread out, constitutes a most serious menace. The precautions which are now taken consist in

the use of iron pipes and iron casings for carrying the wires, whilst at each floor suitable iron doors are provided which are cut to just permit the wires to pass through. The space between the iron plates may be packed with asbestos, the object being to prevent the flame passing from floor to floor *viâ* the casing. The use of gutta-percha wires inside the buildings has been entirely abandoned in favour of wires with non-inflammable coverings.

In the event of a fire which results in the total destruction of a building, it will be obvious that the work of finding the various wires in the many routes radiating from a large office would occupy a very considerable amount of time. To avoid this difficulty the modern practice is to terminate every wire entering the office in either a large underground chamber entered by a fire-proof door, or to build a small fire-proof chamber in such a position and so designed that if the building was absolutely gutted there would be no damage done to the interior of this chamber either by fire or water. Every wire would be in its proper position upon the various cable heads and terminals, and the work of making the temporary arrangements would thereby be reduced to finding suitable accommodation, joining up the instruments and batteries, and then linking the underground chamber with the temporary offices. If every wire had first to be found and, moreover, if the paper cables had been damaged by water for 20, 30, or even 50 yards, the magnitude of the task of cutting and jointing new lengths of wire and terminating the cables would be appalling; meanwhile, the large town and environs would be without telegraphic facilities, possibly for several weeks. It is, therefore scarcely possible to take too great precautions against such a disaster.

In the case of a recent fire, in which the test box and a considerable portion of the instrument room was burnt out, the basement test box proved the salvation of the situation. The secondary cells were intact, and therefore it was only necessary to find suitable accommodation in undamaged parts of the building, and to run leads from the basement test box and from the secondary cell installation and join up the sets of apparatus, which poured in from every part of the kingdom. Had every cable entering the office been damaged by water for a distance of twenty or thirty yards

outwards, the magnitude of the disaster would have been increased twentyfold.

As stated, the latest practice is to terminate each cable, whether paper or G.P. insulated, upon a cable connection box (see Chapter XXII) placed in the external underground chamber. The position of this chamber is usually chosen from the point of view of its proximity to some government or municipal building in which space for the temporary accommodation of the circuits could be found in the event of the Post Office being gutted. The position is also considered from the point of view of safety from falling débris.

From the cable-connection boxes in the external chamber, lead-covered cables with 40 lb. conductors, insulated with silk and cotton, are carried in iron pipes to the test and cross-connection frame in the internal fire-proof room. (In all future installations 20 lb conductors will be used.) The two sides of this frame are linked by wires having a flame-proof insulation,* and 128-wire lead covered silk and cotton cables carry the wires to the test box. Thence to the instrument tables 5- and 7-wire lead covered cables laid in iron troughing, terminated upon 7-tag connection strips, are used, whilst the instrument connections are made with insulated wire similar to that employed for the cross-connections.

Test and Cross-Connection Frame.

The test and cross-connection frame (Fig. 334), which is, of course, varied in size according to the requirements of each case, provides a testing point, a cross-connecting field, and also serves to carry the heat coils and protectors. The cables from the exterior chamber are connected to tags upon the horizontal side of the frame. Each pair of wires passes through two vertically-placed test jacks on to two tags furnished with screws. By inserting the double test peg into the pair of test jacks, both line and both instrument sides are joined to the four conductor cord attached to the test peg. Since it is usually only required to test one of

* One type of flame-proof insulated wire consisted of a tinned copper conductor covered with silicated cotton and worsted. This proving unsatisfactory a new wire was tried consisting of a tinned copper conductor having a thin coating of rubber covered with braided worsted ; the matter is, however, still in the experimental stage.

the circuits, the two conductors of the cord which pick up the wire not to be tested should be joined through at the test tablet before the peg is inserted. The frames usually carry both telegraph and telephone circuits, and, therefore, speaking and testing apparatus permanently connected to the pegs is invariably provided. The testing apparatus is suitable for rough tests, and is of the general form shown in Fig. 354, save that the galvanometer is of the "Test Box" type, and that telephone speaking and ringing apparatus is added.

Fig. 334.—Test and cross-connection frame.

The wires upon the horizontal side are of course arranged in the order in which they come in on the "leading-in" cable. From this point they are connected to the vertical strips of protectors and heat coils by means of 20 lb. conductors having flame-proof insulation.

When any cross is necessary, the cross-connecting or "jumper" wires between the vertical and horizontal sides of the frame are altered, so avoiding the necessity for disturbing the cabling. The purpose of the rings, to be seen in the figure, is merely to provide an orderly method of running these jumper wires.

CHAPTER XIX

THE EDEN MORNING TEST.

THE efficiency of a telegraph system depends to a very great extent upon the efficiency with which the vast number of lines is maintained. The prompt discovery and the rapid removal of faults is of the last importance. Moreover, the detection and removal of *slight* defects before they can injuriously affect the working of the circuits is a consideration, the value of which is, perhaps, but too frequently overlooked. It might be argued that, since a defect or slight fault did not affect the working of the circuit, its existence might reasonably be ignored. In very wet weather, however, this small defect might readily become a pronounced fault, but even supposing that it did not do so, a number of these defects accumulating upon a circuit might easily lead to its total stoppage. In this case, instead of the trouble being due to a single specific fault which could quickly be traced and remedied, there would be several minor defects to be picked out and remedied. This would mean a considerable increase in the duration of the defective condition of the circuit. The results of the week's tests, which are made by the commercial or traffic department, are sent to the engineering department, where they are very carefully scrutinized, and as a result the wires which are below the values obtained in the case of other wires following a similar route, are minutely examined and the cause of the defect removed.

In the case of definite faults, the position of the fault is localized between two adjacent testing stations, as described in the subsequent chapter. The objects of the test may therefore be said to be, firstly, the indication of minor defects which may not immediately affect the working of the

circuit, and secondly, the indication of definite faults, which certainly will affect the working.

Advantages of the Eden Test.

The system of morning testing now in vogue was invented by A. Eden, and presents the following advantages over previous systems :—

1. The whole of the testing apparatus is under the control of the testing office.
2. The test is independent of the exact value of the E.M.F. of testing battery and of the sensitiveness of the galvanometer.
3. The test may be applied to lines differing largely in conductor resistance.
4. Two circuits are tested at one operation.
5. The simplicity and rapidity with which it may be manipulated.

These advantages will be apparent when the principle of the test has been considered.

Method of Demonstrating the Principle.

The general lines upon which the underlying principles of the Eden test will be demonstrated are as follows :—

1. It will be shown that by the application of two 10,000$^{\omega}$ resistances the insulation resistance may be assumed to be equivalent to a single fault at the centre of the circuit equal in value to the joint resistance of all the faults or leaks.
2. It will be shown that if an otherwise perfectly insulated circuit has a fault at the centre of its resistance, the resistance of the fault can be determined from a knowledge of the resistance of the circuit, the value of the current sent out and the value of the current received.
3. It will be shown that, using a battery of given E.M.F., the resistance of the central fault may be determined from a knowledge of the current flowing through the fault and the conductor resistance of the circuit.

Insulation Resistance.

Before entering upon a description of the Eden morning test, it is essential that the exact meaning of the term

"insulation resistance" should be thoroughly understood. The insulation resistance of an open line is the joint resistance of every path along which current can escape to earth. In other words, it represents the joint resistance of all the insulators to the passage of a current over their surfaces. The conductor resistance of a circuit is the resistance of the wire itself. Insulation and conductor resistance are two entirely separate entities, but in certain cases they are *apparently* interdependent.

In order to make this point quite clear, assume that a line of 120Ω resistance is supported upon four insulators, and that the resistance from the line over each insulator is 100Ω. The values chosen are very widely different from those which would occur in practice, but the principle will be

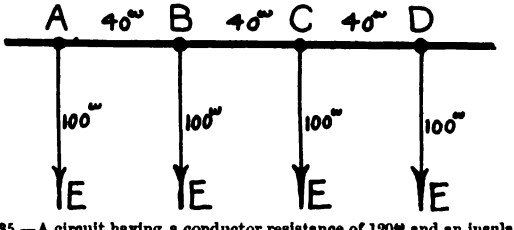


Fig. 335.—A circuit having a conductor resistance of 120Ω and an insulation resistance of 25Ω.

made apparent more simply by the aid of an exaggerated case. The conductor resistance of such a line (Fig. 335) would be 120Ω. The insulation resistance would be the joint resistance of the four insulators, viz. 25Ω. If now the resistance of the circuit as a whole is measured from *A* with the end *D* insulated, the result obtained is 47Ω. This value is termed the "apparent insulation" resistance in contra-distinction to the "true insulation" resistance, which, in the present case, is 25Ω. It will be observed that the conductor resistance has had a very great effect upon the result, and that the insulation resistance will affect the apparent value of the conductor resistance. If the end *D* is earthed, the resistance from *A* is now 45Ω.

Application of High Resistances to the Ends of the Circuit.

If a very high resistance, say 1,000,000Ω, is connected to

each end of the circuit, the resistances of 40$^{\omega}$ between each of the faults becomes quite insignificant, and the circuit is obviously equivalent to one with the four faults in parallel at its centre. Another way of stating the same fact is to say that the same difference of potential will exist across the ends of each insulator. If the difference of potential between the two ends of the circuit were 20·0012 volts, the difference of potential between the ends of the line itself would be but ·0012 volts, or $\frac{3}{1000}$ of one per cent. Had the resistances been 10,000$^{\omega}$ at each end the value would have been rather more than $\frac{1}{2}$% of the total voltage.

Referring back to Fig. 20, the four circuits depicted are in parallel, and their joint resistance was found to be the reciprocal of the sum of their separate conductances. In this case, the difference of potential between the ends of circuits has one definite value and only one value. Were this not the case, either or both the junction points of the circuit would have two or more different potentials at the same time, a condition which is so obviously impossible that demonstration is unnecessary. In the case cited, the joint resistance of the paths is obtained in the manner just stated. Now, wherever the same difference of potential is applied to several circuits from a single battery, the same rule may be applied. In the present case it has been shown that by the application of very high resistances to the ends of the circuit this condition is fulfilled.

The statements will perhaps be rendered more apparent by the graphic representation in Fig. 336. This figure shows the conditions which are met with in practice, viz. a 1000$^{\omega}$ line with 10,000$^{\omega}$ placed at each end. A battery having an E.M.F. of 21 volts has, however, been shown for simplicity of calculation. If the circuit were perfectly insulated, the difference of potential between the ends of the line itself would be 1 volt, *i.e.* 11 volts would be applied to the first insulator and 10 volts to the last one. For practical purposes it might be assumed that no fall existed between the ends of the line, and therefore that the huge number of leaks to earth which occur at the insulators, and which naturally differ in value, are equivalent to a single fault equal to their joint resistance, placed at the centre of the circuit.

Using an E.M.F. of 55·5 volts, the difference of potential

between the ends of the line would be but 2·6 volts as compared with 55·5 volts if the 10,000Ω blocks were omitted. The resistances of the circuit in Fig. 336 have been represented by the lengths of the lines drawn.

Resultant Fault.

It can be proved that the insulation resistance of a uniformly insulated line may be represented by a single fault at the centre of the circuit, and that the value of the resistance of the fault is equal to the joint resistance of all the leaks in parallel. For example, a line 100 miles long would have about 3000 insulators upon it. Assuming that the resistance of each insulator was 10 megohms, and that the resistance of the circuit was 1000Ω, then this line is

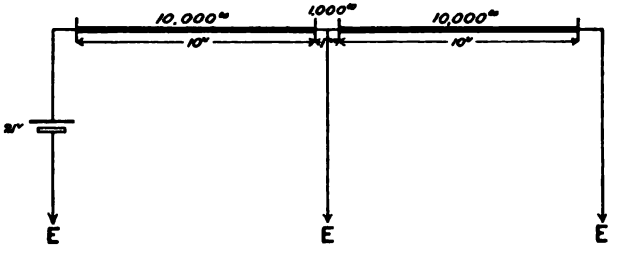


Fig. 336.—Illustrating the way in which the application of two high resistances throws the line into the electrical centre of the circuit.

equivalent to a line having the same conductor resistance (1000Ω) perfectly insulated, save for a fault at its centre (500Ω from each end) equal to $\frac{10,000,000}{3000} = 3333\Omega$. If the line is not uniformly insulated, *i.e.* if the resistance of the various insulators differ, the line may still be represented by a single fault equal to the joint resistance of the various leaks, but its position will not now be in the centre of the circuit.

Summary of Results.

The results of the above investigations may be summarized as follows :—

1. If a circuit is uniformly insulated (example, a gutta-percha-covered wire, or an open line where there is a very

large number of insulators each of practically equal resistance), the insulation resistance may be represented by a central fault equal in resistance to the joint resistance of all the leaks in parallel.

2. If two high resistances are applied to the ends of the circuit so that each fault is tested with approximately the same voltage, then, whether the line is uniformly insulated or not, its insulation resistance may be represented by a single fault at the centre of the total resistance of the circuit equal in value to the joint resistance of all the leaks in parallel.

The rigorous proof of these statements requires the use of higher mathematics, but it is believed that the simple arithmetical examples given should serve to make the truth of the statements quite apparent.

Insulation Resistance per Mile.

At this juncture it will be necessary to define and explain the meaning of the term "insulation resistance per mile." If the total insulation of a circuit fifty miles long had the same value as one twice the length, it would at once be admitted that the longer circuit was in better condition than the shorter. Upon the longer circuit there are twice as many insulators or possible points of leakage, and since the total amount of leakage is the same, there is upon the average half as much at each insulator, *i. e.* the resistance of each insulator upon the longer circuit is twice as much as that of each insulator upon the shorter circuit. From this it will readily be seen that :—

Insulation per mile = Total insulation × Mileage.

For example, if the total insulation of a circuit 83 miles long is 30,000$^{\omega}$, the insulation per mile is 2,490,000$^{\omega}$, or approximately 2·5 megohms. The only case in which this rule does not accurately apply is when the insulation resistance is abnormally low or the conductor resistance is abnormally high. In this case the result obtained by multiplying the total insulation by the mileage is too high. Generally speaking the total insulation resistance, save upon very long circuits, is considerably higher than the conductor resistance, and in that case the rule given is sufficiently accurate for all practical purposes.

When two or more circuits are connected together, either by extension or by forking, the total insulation of the combination is the joint resistance of their separate insulation resistances. The conductor resistance may generally be entirely ignored.

Example.—A circuit is made up by extending a circuit 20 miles long to another 30 miles long. If the total insulation resistances of the two circuits are 40,000$^{\omega}$ and 80,000$^{\omega}$ respectively, what is the total insulation and the average insulation per mile?

$$\text{Total insulation of whole circuit} = \frac{40{,}000 \times 80{,}000}{40{,}000 + 80{,}000}$$
$$= 26{,}700^{\omega} \text{ approximately.}$$
$$\text{Insulation per mile} = 26{,}700 \times 50$$
$$= 1{,}335{,}000^{\omega}$$
$$= 1{\cdot}335 \text{ megohms.}$$

The insulations per mile of the two circuits considered separately are ·8 and 2·4 megohms respectively.

In actual practice it is never required to know the absolute value of the insulation resistance very accurately. A result correct to 10% or even 20% suffices for most cases.

The value of the insulation resistance per mile enables the condition of various circuits to be directly compared. In the case of a route of a dozen wires, the fact that a lower insulation was obtained upon a particular circuit would indicate the presence of a minor defect, and the cause would then be ascertained by examining the line. Again, lines between the same two points, but following different routes, may be very closely compared, since the climatic conditions would be the same, and any considerable difference in the values obtained would indicate that attention was required. The careful scrutiny of the results of the morning tests is a work of very great importance, and by investigating and remedying every abnormality as it arises, the condition of the circuits can be brought to the highest pitch of perfection.

Again, the condition of wires maintained by the different administrations may be compared.

Fault at the Centre of a Circuit.

If the conductor resistance and the values of the currents

sent out and received upon a circuit, having a fault at the centre of its resistance, are known, the resistance of the fault can readily be obtained. Such a circuit is represented in Fig. 337. The current sent out from the battery is 10 m.a., whilst that received at the distant end is 8 m.a. The difference between the current sent out and that received (10—8 = 2 m.a.) is the amount which flows through the fault. The 10 m.a. arrives at *B*, where it divides 8 m.a. to *C* and 2 m.a. through the fault. In Chapter II it was explained that a current divides between two paths in parallel in inverse proportions to their resistances. It will therefore be obvious that since the current splits between the fault and *B C* in the proportion of 2 m.a. to 8 m.a. their

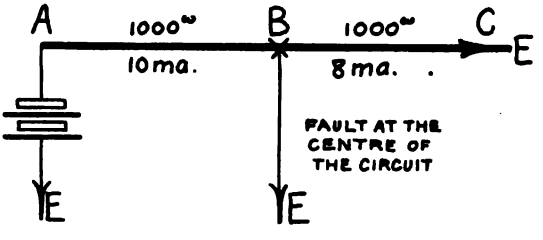


FIG. 337.—Circuit with fault at the centre.

resistances are as 8 to 2 respectively. This at once gives the resistance of the fault as 4000Ω. It is, however, necessary to put the method of obtaining this result into the following more general form :—

Res. of fault : $\frac{1}{2}$ Circuit res. : : Received current : Loss.

The fact that the current splits in inverse proportion to the resistance of two circuits in parallel may readily be proved. Taking the example given in Fig. 337, the difference of potential between *B* and *C*, *i. e.* between *B* and earth, is by Ohm's law ·008 × 1000 = 8 volts. The difference of potential between *B* and *E* *viâ* the fault must obviously be the same, since the point *B* cannot have two values of potential at the same time. The resistance of the fault is, then, $\left(\frac{E}{C} = R\right) \frac{8^{v}}{\cdot 002} = 4000^{\Omega}$.

From this, and the previous explanation, it will be seen that the following relationship is true :—

$$\text{Res. of fault} = \frac{\frac{1}{2}\text{ Circuit res.} \times \text{Received current}}{\text{Loss}}.$$

The numerator gives the value of the potential difference between the centre of the circuit and earth (which is equal to that between the ends of the fault), whilst the denominator is the value of the current through the fault.

RELATIONS BETWEEN "SENT," "RECEIVED" AND "PERFECT" CURRENTS, AND THE RESISTANCE OF A FAULT AT THE CENTRE OF CIRCUIT OF KNOWN RESISTANCE.

If the circuit shown in Fig. 338 were perfectly insulated,

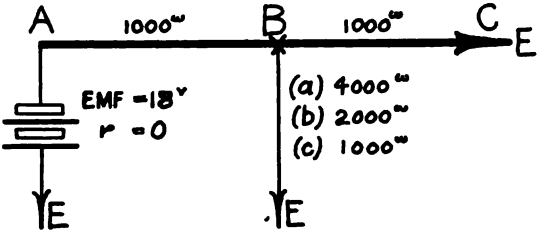


FIG. 338.—Circuit with fault at the centre.

the value of the current flowing through it would be $\frac{18}{2000} = 9$ m.a. This value is known as the "perfect current" for that particular battery and circuit. If now faults, having resistances of (*a*) 4000Ω, (*b*) 2000Ω, and (*c*) 1000Ω, are successively placed at the centre of the circuit, it will be found by actual trial that the following relation is true :—

When a fault is applied to the centre of an otherwise perfectly insulated circuit, for every milliampere of current flowing through the fault half a milliampere more is sent out and half a milliampere less is received as compared with the current sent and received when the current was perfect.

(*a*) Resistance of circuit = 1000 + Joint res. of BC and the fault.

$$= 1000 + \frac{1000 \times 4000}{1000 + 4000}$$

$$= 1800^{\omega}$$

$$\text{Sent current} = \frac{18}{1800} = 10 \text{ m.a.}$$

$$\text{Received current} = \frac{4}{5} \text{ of } 10 \text{ m.a.} = 8 \text{ m.a.}$$

$$\text{Loss} = 10 - 8 = 2 \text{ m.a.}$$

(*b*) Resistance of circuit $= 1000 + \frac{1000 \times 2000}{1000 + 2000}$

$$= 1667^{\omega}$$

$$\text{Sent current} = \frac{18}{1667} = 10{\cdot}8 \text{ m.a. approx.}$$

$$\text{Received current} = \frac{2}{3} \text{ of } 10{\cdot}8 \text{ m.a.} = 7{\cdot}2 \text{ m.a.}$$

$$\text{Loss} = 10{\cdot}8 - 7{\cdot}2 = 3{\cdot}6 \text{. m.a.}$$

(*c*) Resistance of circuit $= 1000 + \frac{1000}{2}$

$$= 1500^{\omega}$$

$$\text{Sent current} = \frac{18}{1500} = 12 \text{ m.a.}$$

$$\text{Received current} = \tfrac{1}{2} \text{ of } 12 \text{ m.a.} = 6 \text{ m.a.}$$

$$\text{Loss} = 12 - 6 = 6 \text{ m.a.}$$

The value of the perfect current is 9 m.a., and therefore in example (*a*) 1 m.a. more is sent out and one less received, in (*b*) 1·8 m.a. more is sent out and 1·8 m.a. less received, and in (*c*) 3 m.a. more is sent out and 3 m.a. less is received. From these results it is apparent that

(1) Sent current = Perfect + $\frac{1}{2}$ loss.
(2) Received current = Perfect − $\frac{1}{2}$ loss.
(3) Perfect current = $\frac{\text{Sent} + \text{Received}}{2}$
(4) Loss = Sent − Received.

The second relation is the one which is now required to

complete the theory of the test. Upon p. 595 it was proved that

$$\text{Res. of fault} = \frac{\frac{1}{2}\text{ circuit Resistance} \times \text{Received Current}}{\text{Loss}}.$$

Substituting for received current the equivalent found above, it will be seen that

$$\text{Res. of fault} = \frac{\frac{1}{2}\text{ circuit Resistance} \times (\text{Perfect} - \frac{1}{2}\text{ loss})}{\text{Loss}}.$$

Application of the Results obtained.

It has now been shown that, knowing the E.M.F. of the testing battery, the circuit resistance and the loss—or current through a fault at the centre of the circuit—the resistance of the fault may be obtained. It has also been explained that by the application of a 10,000$^{\omega}$ coil at each end of the line, the insulation resistance is rendered equivalent to a single fault at the centre of the resistance of the circuit. Therefore, the results obtained in the case of the simple circuit shown in Fig. 338 hold good for the more complicated case which the Eden test represents.

Practical Arrangement for Eden Test.

The wires are wherever possible tested in pairs, their distant ends being looped for the purpose. A current is sent out on the first and received back upon the second wire. If the line be in perfect condition the total current sent out will be received back upon the second wire, but should there be any leakage, its amount is equal to the difference between the sent and received currents. In order to observe the loss, a differentially wound tangent galvanometer (*vide* Fig. 26) is employed, one coil of which is included in the first wire, whilst the second coil is placed in the second wire (Fig. 339). The coils are joined up in such a direction that the sent current opposes the received current, and therefore the deflection indicates the value of the current flowing through the various faults, *i. e.* the loss.

The E.M.F. of the testing battery is always the same, viz. 55·525 volts. From this and the resistance of the line the value of the perfect current can readily be obtained. The

constant of the galvanometer is 80 divisions per milliampere with both coils, or 40 divisions per milliampere for one coil, as in the present test. The preponderance of the sent over the received current amounts to the difference between them upon the sent current coil.

Referring again to the result found upon p. 597 for the simple circuit, it will readily be seen that all the currents must be expressed in the same units, either amperes, milliamperes, or, more important still, in tangent divisions. If the perfect current be expressed in tangent divisions the deflection obtained may be inserted for "loss," and the statement will still be true. For example, taking value of Fig. 337, *q. v.*—

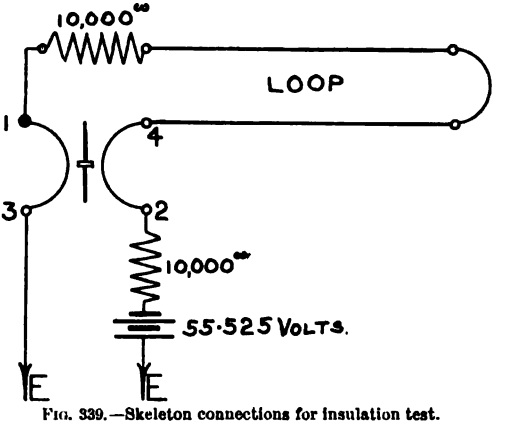


FIG. 339.—Skeleton connections for insulation test.

Perfect current = 9 m.a.
Loss = 2 m.a.
$\frac{1}{2}$ circuit resistance = 1000Ω
Resistance of fault $= \dfrac{1000 \times (9 - \frac{1}{2} \text{ of } 2)}{2}$
$= 4000\Omega.$

Expressing the values in tangent divisions, 40 divisions = 1 m.a., the result obtained is :—

$$\frac{1000 \times (360 - \frac{1}{2} \text{ of } 80)}{80}$$
$$4000\Omega.$$

Before proceeding further it will be useful to give an example of the working out of the insulation resistance of a circuit by the aid of the principles already explained. This should serve the purpose of thoroughly co-ordinating the simple proofs with practical cases.

Example.—If 30 divisions is observed under the conditions of the Eden test upon two looped wires each 50 miles long, and each having a conductor resistance of 10$^{\omega}$ per mile, what is the insulation resistance per mile?

Total resistance of circuit:—

Two 10,000$^{\omega}$ coils	= 20,000
Two coils of galvanometer	= 320
Internal resistance	= 30
Res. of line wire (100 × 10)	= 1,000
	21,350

$$\text{Perfect current} = \frac{\text{E.M.F.}}{\text{Total Res.}} = \frac{55{\cdot}525}{21{,}350} \text{ amperes}$$

$$= \frac{55{,}525}{21{,}350} \text{ m.a.}$$

$$= \frac{55{,}525 \times 40}{21{,}350} \text{ tangent divisions}$$

$$= 104 \text{ tangent divisions}$$

$$\text{Total insulation} = \frac{(\tfrac{1}{2} \text{ cct. res.}) \times \text{Perfect} - \tfrac{1}{2} \text{ loss})}{\text{Loss}}$$

$$= \frac{(\tfrac{1}{2} \text{ of } 21{,}350) \times (104 - \tfrac{1}{2} \text{ of } 30)}{30}$$

$$= \frac{10{,}675 \times 89}{30} = 32{,}000^{\omega} \text{ approx.}$$

$$\text{Insulation per mile} = \text{Total insulation} \times \text{mileage}$$

$$= 32{,}000 \times 100$$

$$= 3{\cdot}2 \text{ megohms.}$$

Verification of the E.M.F. of the Testing Battery.

In the description of the test it has been assumed that the constant of the galvanometer was 80 divisions per milliampere with both coils, and that the E.M.F. of the testing battery was 55·525 volts. The former is secured by joining

up the standard cell and proceeding as detailed in Chapter III. Having adjusted the galvanometer, the testing battery is joined up through 20,000Ω and the circle coil of the galvanometer. If its E.M.F. is 55·525 volts a deflection of 110 divisions will be produced.

$$\frac{55{\cdot}525}{20{,}190} = 2{\cdot}75 \text{ m.a.} = 110 \text{ divisions.}$$

If the E.M.F. of the testing battery is less than this value an additional cell is joined up. This cell will increase the deflection by $1\frac{3}{4}$ divisions. This adjustment is quite fine enough for all practical purposes.

Interpretation of the Results of the Tests.

The value of the perfect current for any particular circuit is a constant quantity, since the variations in the resistance of the line part of the circuit due to changes of temperature are an extremely small fraction of the total resistance. The mileage of the circuit is also a fixed quantity, and it will therefore be seen that tables may readily be prepared giving the insulation resistance per mile for any deflection observed upon each particular circuit. In practice this is frequently done, but a separate table is required for each wire, save where the particulars of two or more circuits agree as regards conductor resistance and mileage.

A table has been printed showing every deflection from 1 to 200 divisions, and opposite each deflection is given the number of divisions which would be observed upon lines having different conductor resistances. If 80 divisions of loss were observed upon a 500Ω line, this reading would be equivalent to 81 divisions upon a line of 1000Ω resistance. In this way the errors due to the difference in the conductor resistance of the circuit are eliminated.

Having made the correction for conductor resistance, the value of the insulation per mile is read off opposite the corrected deflection under the mileage of the loop.

To give a specific instance. Suppose that the reading upon a loop of 2000Ω resistance is 72 divisions, and that the length of the loop is 20 miles.

CONDUCTOR RESISTANCE CORRECTION TABLE.

Actual Reading.	Resistance of loop.		
			2000Ω.
72			74

Deflection which would be obtained upon a 500Ω line if the insulation were the same.

EQUIVALENT MILEAGE.

Reading on 500Ω loop.	Mileages.	
	20	
	Megohms per mile.	
74	·2	

CONNECTIONS.

The various connections required are made by means of an 8-terminal 4-position switch and two test hole switches. The connections as a whole are shown in Fig. 340, and will readily be understood by the aid of Figs. 341 to 348.

ROUTINE OF THE TEST.

In carrying out a series of tests the following procedure is observed—

1. The constant of the galvanometer is taken, the switch and U links being placed as shown in Fig. 341. The skeleton connections are shown above.
2. The E.M.F. of the battery is verified by placing the switches as shown in Fig. 342.

Operations 1 and 2 only need to be performed once immediately before readings are to be taken.

3. The reading upon the loop is taken as shown (Fig. 343).

Each of these operations has been dealt with, and further description is unnecessary.

Prior to taking the reading specified in paragraph 3, the circuits are tested with the test box galvanometer and battery in order to make certain that they have been looped at the distant end.

Eden Test for Position of a Fault.

If the reading obtained in paragraph 3 is so high as to

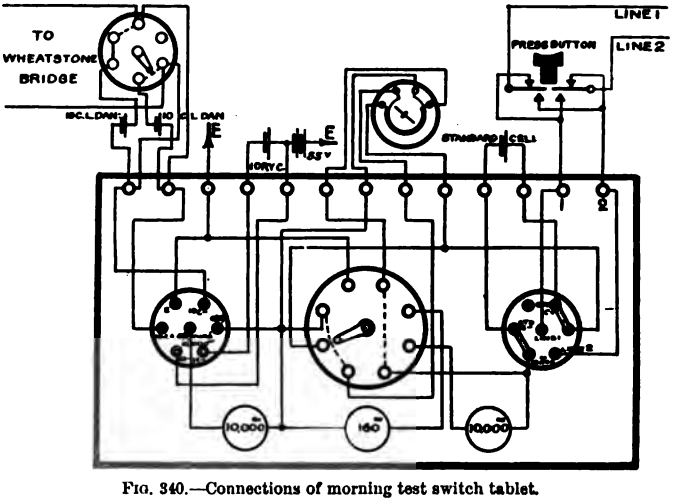


Fig. 340.—Connections of morning test switch tablet.

indicate the existence of a fault the switch is turned to position 4, which makes the connections shown in Fig. 344. If the fault is upon the left-hand wire the needle is deflected off the scale, whilst a fault upon the right-hand wire would cause a deflection on the scale. A fault at the looping office would produce no deflection, since the resistance of each wire to the fault would be the same, and equal currents would flow through both coils of the galvanometer. In the event of a very small deflection it will be evident that the fault is very close to the looping office, and in such cases it is desirable to make sure which is the faulty wire by an independent test.

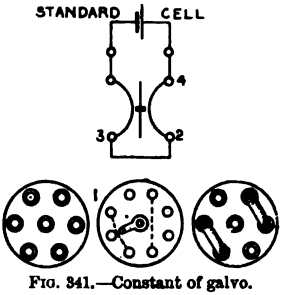


FIG. 341.—Constant of galvo.

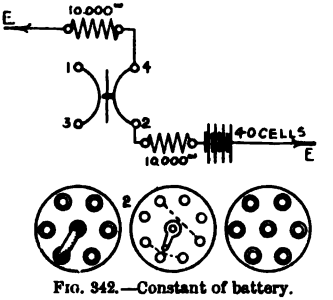


FIG. 342.—Constant of battery.

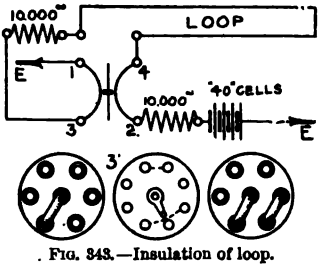


FIG. 343.—Insulation of loop.

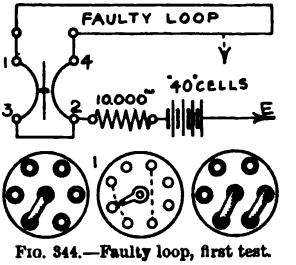


FIG. 344.—Faulty loop, first test.

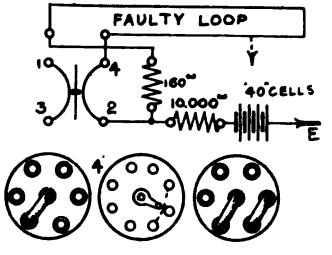


FIG. 345.—Faultly loop, second test.

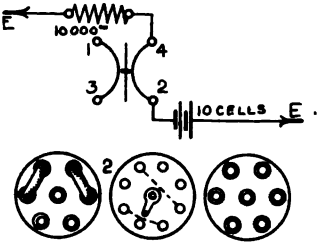


FIG. 346.—Constant of 10-cell battery.

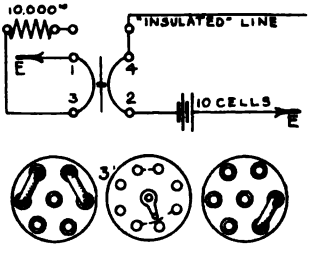


FIG. 347.—Localization testing.

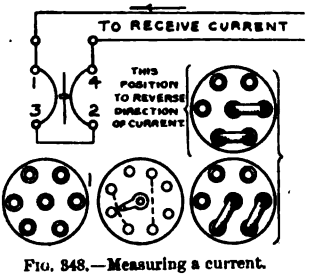


FIG. 348.—Measuring a current.

If the value of the deflection be noted, the switch then turned to position 4, and the new deflection observed, the position or distance of the fault from the testing office may be found. The connections made in the second case are depicted in Fig. 345. The two observations respectively give the difference in the currents flowing in each wire, and the value of the current flowing in the left-hand wire. Knowing this, the ratio between the values of the currents flowing in the two wires is obtained.

In Chapter II it was shown that the current divides between two paths in inverse ratio to their resistances. The resistance of one path is the resistance of the line up to the fault, plus the resistance of one coil of the galvanometer, whilst the other is equal to the resistance to the fault along the other wire plus one coil of the galvanometer.

Example.—With a loop of 3000$^{\omega}$ deflections of 40 and 120 divisions are obtained under the conditions of the Eden localization test.

Current through right-hand wire = 120 divisions

„ „ left „ „ = 120 − 40 = 80 divisions

80 : 120 :: Res. of right-hand wire to fault : Res. of left-hand wire to fault

80 + 120 : 120 :: Total loop resistance : Res. of left-hand wire to fault

5 : 3 :: 3320 : Res. of left-hand wire to fault

Res. of left-hand wire to fault = 1992$^{\omega}$

Deducting the resistance of one coil of the galvanometer } = 1832$^{\omega}$

The result may be obtained direct from the following formula, which has been constructed upon the basis of the reasoning employed above :—

$$\text{Res. to fault} = \frac{(\text{Loop} + 320) \times \text{Larger deflection}}{\text{Twice larger} - \text{Smaller deflectn.}} - 160.$$

Putting in the values used in the example—

$$\text{Res. to fault} = \frac{(3000 + 320) \times 120}{(2 \times 120) - 40} - 160$$

$$= 1832^{\omega}.$$

This test will generally give results which are accurate to within 2% in fine weather, but in the event of two faults existing simultaneously, or if the general insulation of the loop is so low as to bring the resistance of the fault within range of the conductor resistance, or for a very high resistance fault, the test is quite valueless.

At many of the larger offices a press-button is used to reverse the wires in the event of a deflection being in the opposite direction to the divided scale. This arrangement is shown in Fig. 340, but where this is not provided it is necessary to reverse the wires at the test box. If this is done, *both* readings should be taken with the line in the same position when making the fault localization test.

Test for Single Wires.

When a loop cannot be formed the distant office earths the wire to be tested through a resistance of 10,160Ω. The deflection observed then is the sent current. By the aid of the relations found upon p. 596 it will be seen that the sent current less the perfect current gives half the loss. Therefore the relation may in this case be written—

$$\text{Insulation} = \frac{\frac{1}{2}\text{ circuit Res.} \times (\text{Twice Perfect} - \text{Sent})}{\text{Twice (Sent} - \text{Perfect)}}$$

Localization Tests with the Tangent Galvanometer.

For localization tests and other purposes it is frequently necessary to measure the total insulation of a line. This is provided for by a 10-cell Daniell battery, which may be joined up with one coil of the galvanometer to the line to be tested. The E.M.F. of the battery is, roughly, 10 volts, and this serves for the rapid but approximate measurement of resistances between 2000Ω and 400,000Ω.

First, the connections shown in Fig. 346 are made by placing the switches as shown. The deflection, which would probably be about 40 divisions, is noted. Turning the switch to position 3 results in a deflection which depends upon the insulation of the line.

Ohm's law states that if the E.M.F. in a circuit is constant the current is inversely proportional to the resistance. In this case the total resistance in the first case (position 2)

was, allowing 40ω for the battery, 10,000 + 160 + 40 = 10,200ω. This produced a deflection of, say, 40 divisions, and therefore 1 division would be produced through 40 × 10,200 = 408,000ω. The value of the insulation of any circuit tested is therefore equal to this number divided by the deflection observed.

$$\text{Insulation} = \frac{10{,}200 \times \text{Constant}}{\text{Deflection.}}$$

Example.—What is the insulation of a line which gave a deflection of 78 divisions? Constant of galvanometer 39 divisions.

$$\text{Insulation} = \frac{10{,}200 \times 39}{78} = 5{,}100\omega.$$

By means of the 6-terminal 2-position switch the two 10-cell batteries may be connected in series or in parallel. When in series the deflection obtained in an insulation test is, of course, twice that when the cells are in parallel. The real object of the switch is to provide a 20-cell battery for Wheatstone bridge tests.

To measure a current the connections shown in Fig. 348 are made by means of the switches. In this case the value of the current is obtained as explained in Chapter III, the galvanometer constant being ascertained in the usual way by means of the standard cell.

The process of taking the tests has been very greatly expedited by the introduction of a special switch. The loops pass through switch springs before going to the line test box, and by the insertion of a plug the wires are disconnected from the test box and connected to the testing apparatus. Besides the names of the circuits, the times at which the tests are made is noted upon the labels above each switch spring. Also a device has been embodied in the switch for the looping of the various wires in the required order for tests which other offices are making. To loop the wires a plug is withdrawn, and so a considerable amount of time is saved.

It has previously been pointed out that provision is made for these tests upon boxes of the switch-spring type by the addition of the looping strips.

Effect of Insulation Resistance upon the Speed of Working.

Whenever the total insulation of a circuit falls below the conductor resistance, the working speed of the circuit is reduced. In the case of short lines, the insulation may fall to an extremely low value before any trouble results, since the conductor resistance of the circuit is low, and the theoretical maximum working speed far in excess of the possible working speed, as limited by that of the apparatus used. For example, a 400 lb. iron wire circuit has a conductor resistance of 666ω, and therefore the insulation might fall to ·033 megohm per mile. With a circuit 200 miles long the conductor resistance is 2664ω, and to have a total insulation resistance of 2664ω the insulation resistance per mile must be ·53 megohm. If the length is 400 miles the insulation per mile required is 2·13 megohms—a value which cannot be obtained during wet weather. The remedy is, of course, to use a wire of lower conductor resistance. The point to be noticed is that the longer the circuit the higher is the character of the insulation needed. It may again be pointed out that an insulation resistance in excess of the value given by this rule does not reduce the working speed.

Opposite each wire upon the test sheet is given the value of the insulation resistance per mile, corresponding to a total insulation equal to the conductor resistance. This is termed the "working standard" of the circuit. Where a route of wires contains both long and short lines, the whole of the wires are, of course, maintained at the values required upon the longest circuits. The minimum standard of insulation for open lines, known as the "maintenance standard," is $\frac{1}{6}$ megohm per mile, but, as has been shown, this value is inadequate to the needs of long circuits, and therefore the condition of any circuit falling below either the working or the maintenance standard is unsatisfactory.

CHAPTER XX

LOCALIZATION AND SPECIAL TESTING AND THE FORMATION OF SPECIAL CIRCUITS.

PART I. LOCALIZATION TESTS.

Organization.

BEFORE entering upon the details of the various electrical tests, which it is the main object of this chapter to expound, it is desirable that the general scheme of fault localization should be rendered apparent. The efficiency of a telegraph system so largely depends upon the prompt discovery and removal of faults that too much attention can scarcely be paid to the subject.

The Telegraph service, as a whole, is divided into two divisions—the commercial or traffic side and the engineering side. The former controls the actual telegraphic transmission of messages and in addition makes all morning and localization tests, the results of these tests being advised to the Engineering Department. In the latter department the linemen are responsible for the removal of faults and for the satisfactory maintenance of the batteries and apparatus generally.

When the morning test reading indicates the existence of a fault, its position is ascertained by localization tests. For this purpose the circuits are led through test boxes in some or all of the Post Offices *en route;* the general plan being to so arrange the distances between successive testing points, that a lineman can walk over and carefully examine the section of line in less than a full working day. Where this is not possible a lineman will walk from each end of the line to some intermediate point previously determined. In any case, the arrangements made are such

that the clearance of a fault in any section of the line can be accomplished upon the first day of the occurrence of the fault. Sometimes test boxes are placed upon the poles so that a further localization test can be made by having a lineman at that point when required (see Chapter XXII). In the event of a heavy gale it is usual to send men through every main line without waiting for specific advices of faults. An approaching gale generally gives quite sufficient warning for this to be done.

Underground wires are far less subject to faults than open lines, but their cost and electrical inefficiency for high speed working renders their universal adoption quite impracticable. In very large towns there is frequently no alternative, and as a result there are few long lines which have not one or more short sections of underground. In these cases the faults which occur are almost invariably upon the open sections, but when doubt exists a test is made to the pole test box at the end of the underground section.

The position of every fault is localized between two successive Post Offices *en route*. A book, in which every wire is entered together with the names and stations of the officers responsible for the good working of each length of the circuit, is kept near the test box at each testing office. When the fault has been localized this record is consulted and the officers responsible for the good working of the circuit are advised by service message.

If during the day a wire is reported faulty by the telegraphist in charge of the circuit, the test clerk at once proceeds to ascertain the position of the fault, but, before dealing with the line itself, makes quite certain that the fault is not in the apparatus or the leads from the instrument to the test box. This applies to every class of fault.

Various Types of Fault.

Faults may be divided into three classes, viz. earths, disconnections, and contacts. In each of these classes the faults differ in degree and the terms full and partial are used to respectively describe the very pronounced, and the slight faults, in the case of earths and contacts. The

disconnection faults range from a total disconnection down to a partial disconnection or even a "loss of conductance," which means simply a few ohms increased resistance due to an unsoldered or "dry" joint as it is termed.

A fault may be in continuous existence or it may only appear at intervals. The latter class of fault is indicated by prefixing the word "intermittent" to the description of the fault. For instance, the terms "intermittent contact" or "tapping contact" mean a contact which only occurs at intervals.

Preliminary Notes.

Localization tests are considerably facilitated by the use of the test box galvanometer and its accompanying switch. The details of this instrument will, however, more suitably follow the description of the tests themselves, since it

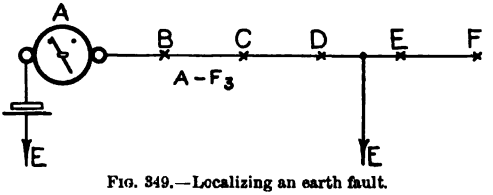


Fig. 349.—Localizing an earth fault.

will then only be necessary to indicate how the switch effects the various connections required for localizing each type of fault.

The name of every office is abbreviated by allotting codes consisting of either two or three letters; for instance, *TS*, *GW*, *BE*, and *SSZ* denote respectively London, Glasgow, Belfast, and Hanley. Where more than one circuit is provided between the same pair of terminal offices the circuits are distinguished by numbering from 1 upwards. For instance, $TS\text{-}GW_2$ denotes the second circuit between London and Glasgow. A similar procedure has been adopted in the case of the imaginary No. 3 circuit between *A* and *F* which passes through *B*, *C*, *D*, and *E* *en route*.

Earths.

In order to localize an earth fault the line is successively disconnected at the various testing points, and it is then

ascertained up to which point the circuit is perfect and beyond which point it is defective. For this purpose an earthed battery and galvanometer are joined to the wire as shown in Fig. 349. The wire is first disconnected at *F*, and the degree of the fault judged. Where the fault is of a very slight character its resistance is indicated by stating the number of tangent divisions observed under the conditions of Fig. 347 (Chapter XIX).

Leaving the wire disconnected at *F*, *E* is next requested to "dis. A-F_8." Upon receipt of this reply from *E* ("A-F_8 dis."), the wire is again tested by applying the earthed battery and galvanometer. In the present case the galvanometer is deflected, thus indicating that the fault exists between *A* and *E*. *D* is now requested to disconnect the circuit, and upon again testing the earth fault has dis-

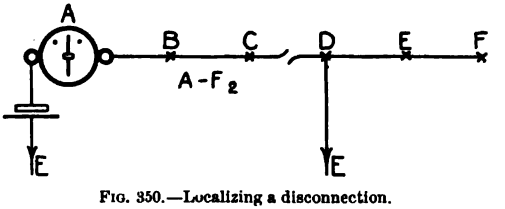


FIG. 350.—Localizing a disconnection.

appeared. In other words the circuit is clear *A* to *D*, but faulty *A* to *E*, therefore the fault is between *D* and *E*.

In the case of earth faults it is advisable to have the circuit successively disconnected from the terminal towards the testing station. If this is done there is no need to await replies that the circuit has been joined through by the various offices. For example, let the test be made in the other direction. After *B* disconnects it would be necessary to await *B*'s reply to the request to put the circuit through before the next test could be made.

DISCONNECTIONS.

The various offices *en route* are successively requested to earth the wire and the earthed battery and galvanometer applied as in the case of earth faults. In the present instance the presence of a deflection proves the continuity of the circuit between the two testing points, whilst the

absence of a deflection denotes the presence of a disconnection in the section under test.

A central office may be asked to earth the wire so as to reduce the number of tests required. An example of the procedure in localizing a disconnection upon A-F_2 may be of service.

Message sent. To *C*. Earth A-F_2. From *A*.
Reply received. To *A*. A-F_2 earthed. From *C*.
Test. Deflection results, therefore the circuit is clear between *A* and *C*.
Message sent. To *C*. Put A-F_2 straight. From *A*.
Message sent. To *D*. Earth A-F_2. From *A*.
Reply received. To *A*. A-F_2 straight. From *C*.
Reply received. To *A*. A-F_2 earthed. From *D*.
Test. No deflection, therefore the fault is between *A* and *D*. In conjunction with the first test this proves the fault to be between *C* and *D*.
Messages sent. The officers responsible for the defective section of line are advised.
Message sent. To *D*. Put A-F_2 straight. From *A*.
Reply received. To *A*. A-F_2 straight. From *D*.

Contacts.

It should first be ascertained that the contact is not in the leads from the instrument to the test box. If such were the case the instruments would of course affect each other when both wires were disconnected at the test box. In large offices, where the instruments are beyond view from the test box, the instrument side should be tested in the same way as the line.

To test for a contact an earthed battery is connected to one line and an earthed galvanometer to the other. If the two wires are in contact the galvanometer is deflected. A battery and galvanometer joined in series (*i.e.* without an earth connection) with the lines is not satisfactory, for the reason that an earth fault upon each of the lines would give the same result as a contact and a wrong locality could very easily be given. The condition is illustrated in Fig. 351, where a wire going due west would be found to be in contact with one going due east, whereas two earth faults only exist. If two such wires were found to be in contact the fault could only be in the leads from the test box to the

two routes, or possibly the wires might travel together in a common direction for a short distance, thus the length in which such a fault could occur would be well known to engineering officers. The addition of the earth connection between the galvanometer and the battery, as in Fig. 352, ensures that a deflection shall result only when the two wires under test are in contact.

An example of a localization test taken from *C* is appended, together with the routine details (*vide* Fig. 352).

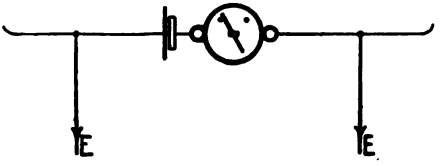


FIG. 351.—Illustrates necessity for earth connection when testing for contact.

The A-K_1 wire travels with the C-M_2 wire between *C* and *H*, passing through *D*, *E*, *F*, and *G en route.*

1. *Message sent.* To *H.* Dis. A-K_1 and C-M_2. From *C.*
   Reply received. To *C.* A-K_1 and C-M_2 dis. From *H.*
   Test. Deflection. Fault exists between *C* and *H.*

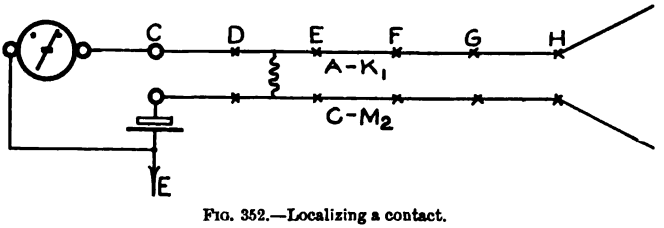


FIG. 352.—Localizing a contact.

2. *Message sent.* To *G.* Dis. A-K_1 and C-M_2. From *C.*
   Reply received. To *C.* A-K_1 and C-M_2 dis. From *G.*
   Test. Deflection. Fault exists between *C* and *G.*
3. *Message sent.* To *G.* Join up A-K_1 and C-M_2. From *C.*
   Message sent. To *E.* Dis. A-K_1 and C-M_2. From *C.*
   Reply received. To *C.* A-K_1 and C-M_2 through. From *G.*
   Reply received. To *C.* A-K_1 and C-M_2 dis. From *E.*
   Test. Deflection. Fault exists between *C* and *E.*
4. *Message sent.* To *E.* Join up A-K_1 and C-M_2. From *C.*

Message sent. To *D*. Dis. A-K_1 and C-M_2. From *C*.
Reply received. To *C*. A-K_1 and C-M_2 through. From *E*.
Reply received. To *C*. A-K_1 and C-M_2 dis. From *D*.
Test. No deflection, therefore the fault exists between *D* and *E*.

5. *Message sent.* To *D*. Join up A-K_1 and C-M_2. From *C*.
Reply received. To *C*. A-K_1 and C-M_2 through. From *D*.
Test. The continued existence of the fault may be verified as the wires are still disconnected at *H*.

Messages sent. The offices responsible for the defective section are advised "A-K_1 and C-M_2 contact *D* and *E*."

Either of the two wires may be worked by disconnecting the other, and if it were decided to work A-K_1, then *H* would be advised to put this through, and C-M_2 would be left disconnected at the box or disconnected at *D* and *E*. If a spare line between *D* and *E* is available a cross could be made and both circuits worked.

It is the practice to periodically test all faulty circuits to see if the fault has been removed, thus ensuring that the wires shall not needlessly remain idle.

It will be seen that localization tests are of an extremely simple character, but the care with which they should be performed can hardly be understated. A mis-test, *i. e.* the reporting of a fault to exist in a wrong section, entails the examination of that section by the lineman, and it may not be found out that a mistake has been made until it is too late to get the fault removed upon the same day. Again, where a large number of tests are being made, the work must be done systematically, and attention is directed to the importance of receiving replies that particular operations have been performed before proceeding further with the tests. Moreover, a considerable local knowledge of the routes taken by the various circuits is highly desirable, as it tends to expedite the process of testing and advising the existence and locality of faults.

Intermittent Faults.

Faults of this class require the very greatest care in

localization in order to avoid mis-tests. They are localized in precisely the same manner as the permanent faults already dealt with. If the fault is an intermittent earth the circuit is disconnected successively and it is ascertained by carefully watching for its re-appearance that it occurs when the wire is disconnected at one point and does not do so when the disconnection is one office nearer the testing station.

Where the wire cannot be given up for prolonged tests the locality may be ascertained by crossing successive lengths of the circuit with those of another circuit known to be in perfect condition.

For example, let A-F_3 (Fig. 349) be the faulty circuit and let A-F_2 (Fig. 350) be known to be in perfect condition. It is assumed that the fault does not very seriously affect the circuit and that the traffic is so heavy as to render it inconvenient to give up the circuit for testing purposes.

The following notes contain a summary of the operations involved :—

1. *B* is requested to cross A-F_2 and A-F_3 at —— (a time is given such that the message can easily be attended to at the time stated).

2. At the given time *B* makes the cross and *A* also crosses the two lines. If the fault re-appears on A-F_3 the fault is beyond *B*.

3. *C* is next told to cross the wires, and at the time given this cross is made and the wires put straight at *A*. If the fault now appears on A-F_2 it is evident that it is between *B* and *C*.

If the crosses are made rapidly and punctually, the circuits should not be interrupted for more than one minute for each cross. Generally speaking, this method finds little favour, and it is only adopted when the faulty circuit cannot be spared and a wire cannot be given up to cross with it.

Covered Wire Faults.

Earth faults upon covered wire circuits have certain well known and distinctive symptoms which differentiate them from faults upon aërial lines. A wire may be found to be below standard when tested in the morning, and with a small power, say 10 or even 20 cells, the circuit may

appear to be almost perfect, although giving a better result with a positive than with a negative current. If the power is increased to 100 volts there is a marked difference in the insulation when tested with positive and negative currents respectively. With the former the wire appears fairly good, but almost to full earth with the latter. Immediately the negative current is applied the deflection gradually increases in value until a condition approaching full earth is observed. By reversing the battery the deflection just as gradually falls, indicating a greatly increased resistance.

The explanation of the phenomenon is that a current flowing from the wire through the fault to earth forms an oxide of copper at the fault. This oxide, being an insulator, covers up and more or less perfectly insulates the fault. The reverse current, upon the other hand, reduces the oxide and keeps the wire clear, so decreasing the resistance of the fault.

It will be noticed that in nearly all tests the zinc or negative pole of the battery is connected to line, so that any covered faults may not be masked by the insulating action which would result from the use of a positive current.

Frequently a covered fault will wholly prevent the working of a long circuit, whilst it would have little or no effect upon the working of a very short or local circuit. In such cases a cross at the office and the end of the underground section will be highly beneficial, since the local office has only a very small power and also because the effect of a fault is felt far less. The effect of a fault of say 1000$^{\omega}$ resistance would be comparatively slight upon a local circuit with a line resistance of 50$^{\omega}$ or 100$^{\omega}$, whilst its effect upon a circuit of 2000$^{\omega}$ resistance would be such as to produce a total stoppage.

The practice of testing covered faults with very large powers (such as 100 Bichromates) is to be deprecated, since it is likely to result in the development of several other minor defects into pronounced faults. Such a power, if applied to an Atlantic cable, would probably be quite sufficient to develop enough faults to occupy a cable-ship for years.

Test Box Detectors.

The various tests described are greatly facilitated by the use of the "Test Box Detector" (Fig. 353). The galvanometer is of the ordinary pattern, but a switch is added for the establishment of the various connections with the testing battery. This switch consists of four quadrants within a ring, and so arranged that any quadrant may be plugged to the ring or any quadrant may be connected to the quadrant horizontally or vertically opposite, but not diagonally. The four terminals marked *C*, *G*, *E*, and *Z*, are joined up at the back of the instrument in the manner shown, whilst the three lower terminals are used for the various tests.

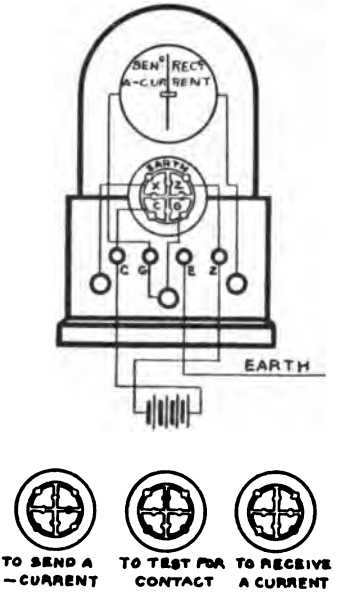


Fig. 353.—Test box detector.

The resistance of the Test Box Detector is 200$^{\omega}$ and its figure of merit is 3·06 m.a., with which it should deflect to between 20° and 30°. With 20 Daniell cells a full deflection would result through about 2000$^{\omega}$.

The combinations which may be effected are as follows:—

1. To send a negative current, plug *C* and earth and *Z* and *G*. The wire is then connected to the right-hand terminal.

2. To send a positive current plug *Z* and earth and *C* and *G*.

3. To receive an earthed current plug *G* and *E* and connect the right-hand terminal to the wire upon which the current is to be received.

4. To observe a current upon a through wire the right and centre terminals are connected to the two sides of the circuit and all the plugs removed.

5. To test for contact plug X and Z, C and earth, and G and earth, the test being made by connecting the faulty wires to two outer terminals.

The arrangement which is used upon one-panel test boards of the switch-spring pattern is shown in Fig. 354. The galvanometer is of the test box pattern termed a "test box detector C," and the 7-test-hole tablet is mounted alongside. Each test hole is connected and lettered as indicated in the figure, and consideration will show that any of the combinations required may readily be obtained by the aid of the U-links.

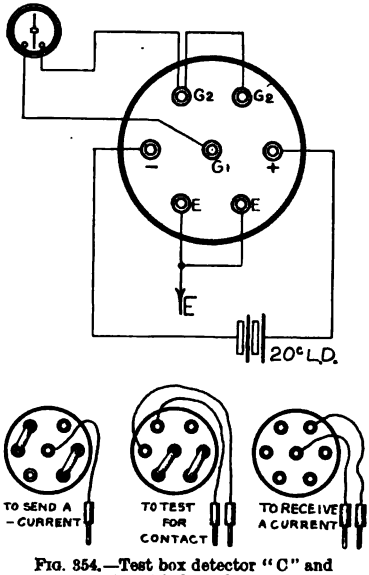


FIG. 354.—Test box detector "C" and 7-test-hole tablet.

Upon switch-spring boards larger than the one-panel size a test tablet having 22 test holes is placed upon the rail between the panels. The upper portion, containing 8 test holes, is used for connecting the tangent galvanometers and Wheatstone bridges to the lines for periodic and special tests. The lower set of 8 holes is connected to the test box speaking sets and calls for no further comment. The central tablet provides precisely the same facilities as the 7-test-hole tablet just considered, and the method of making the various combinations should be quite apparent from Fig. 355. The galvanometer is of the ordinary differential pattern and is mounted upon a turntable bracket above the test hole tablet (see Fig. 316).

In telephone trunk exchanges, the 7-test-hole tablet allied with a differential galvanometer is frequently employed; the connections are, however, slightly different to those previously considered, but as they are indicated by the engraving, and since the arrangement has seldom, if

ever, been used upon telegraph test boards, it will suffice to mention its existence. Yet another method of connection has been adopted upon the testing case in the test and cross-connection frame chamber, but this is largely due to the fact that both telegraph and telephone circuits are provided for.

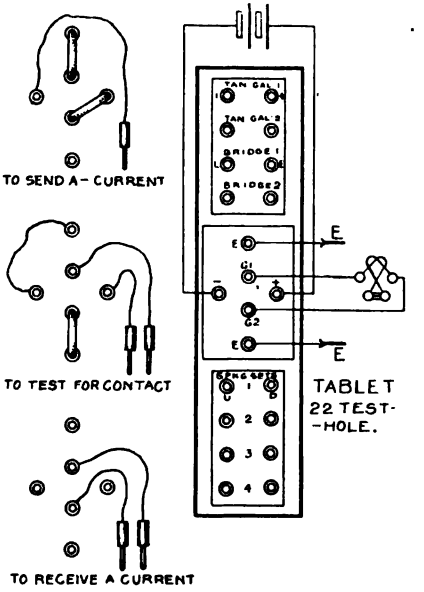


FIG. 355.—Test tablet (22-test-hole) used upon the larger switch spring test boards. Connections required for localization testing are shown on the left.

CAUSES WHICH PRODUCE FAULTS.

As a conclusion to this section of the chapter it will be of interest to briefly consider the causes which produce faults upon the lines. The explanations will, however, assume some knowledge of the subsequent chapters, and this section may with advantage be re-read after construction has been considered. Faults upon aërial lines will be dealt with before, and separately from, underground faults.

With earth faults the degree is, of course, often dependent upon the climatic conditions, and a fault which in fine

weather is slight may become full or total in wet weather. Moreover, the longer the circuit the greater is the deleterious effect of an earth fault of given resistance. Its effect also varies with its position, being most felt when in the centre and least when at the ends of the circuit.

A full earth may be produced by the line wire, released from the insulator, touching the earth wire upon the arm or by contact with any part of the metal upon an iron pole. The same effect results from the line wire coming into contact with anything which forms a good earth connection, such as a stay wire. With iron wire circuits the binding sometimes gives way, due to corrosion, and the effect of the wind releases the line wire. Again, the insulator may be broken by stone-throwing, a practice which cannot be entirely stamped out, notwithstanding the efforts of the police and the frequent prosecutions which result.

Much difficulty is caused by the proximity of trees, and in wet weather a very pronounced fault may be caused by the line wires becoming entangled with the branches. Along country roads it is most difficult to avoid the trees which overhang the footway, and occasionally some difficulty is experienced in obtaining permission to cut away the branches which jeopardize the satisfactory working of the circuits. Serious break-downs resulting in the total stoppage of a route are usually caused by trees being uprooted by a gale and blown over upon the line.

Earth faults of a slight character are often caused by broken or cracked insulators—usually the result of stone-throwing. When the line wire is released and rests upon a dry portion of the wooden arm, remote from the earth wire, the resultant fault is not of a very pronounced character. Similar remarks apply to contacts between the wires and the branches of a tree. In fine weather these defects are of a slight character, but during the prevalence of rain become much more pronounced.

Intermittent faults are produced by any of the causes mentioned, but the conditions are varied by the wind causing the wire to move. A wire may be blown into contact with a stay by each gust of wind, or conversely the stay may be brought into contact with the line by boys swinging upon the stay wire or by cattle rubbing against it. Again, the gusts of wind may blow the wires

into contact with the branches of a tree, for it must be remembered that the wires may be swung outwards to a distance almost equal to the amount of their sag or dip. Some of these intermittent faults result from the most extraordinary and unlooked for causes, but it would scarcely be profitable to give a long list of these happenings.

Contacts are produced by defective regulation of the wires or by a wire, released from its binding, making contact with one of the other lines. Also, contacts very frequently result from pieces of wire, chain, kite-strings, etc., being thrown over the wires. If a piece of wire or chain lies upon the roadway it is only a question of *how* long it will be before it is thrown on to the wires, and this is why telegraph foremen and linemen are so careful never to leave any odd pieces of wire upon the road. In wet weather string and cotton produce a fairly effective contact.

The absence or defective condition of the earth wires upon a long line produces "weather contact" (*q.v.*), whilst a defective earth at a telegraph office results in an apparent contact between all the circuits. Slight contacts are usually produced by substances of low conductivity being thrown across the wires. In one case (in England) such a fault was found to be caused by the dead body of a snake!

Intermittent contacts usually result from the action of the wind, and the wires are blown together at each gust, or a chain or a piece of wire depending from one wire swings into contact with another. But little imagination is needed to indicate how many possible variations of these effects may produce faults.

A disconnection is caused by the breakage of the wire, which may be due to defective joints, defective regulation, natural decay of the wire produced by the action of the elements or by chemical fumes with which the air in the particular locality is laden. Again, the wires may be broken during blasting operations, near rifle ranges, or by trees, chimneys, or other objects falling upon the line. Defective joints are comparatively rare, but it is open to some question whether defective regulation is equally rare as the primary cause of fractures. It will usually be found that workmen pull the wires up too tightly, with the result

that, in very cold weather, a serious stress results. When the renewal of the wire has been too long delayed breakages occur at the weakest positions, but it may be pointed out that, if the gauge of a wire is *uniformly* reduced by oxidation, the factor of safety remains unaltered, because the weight of the wire per unit length, and therefore the stress upon it are both correspondingly lessened. With copper wire erected in country districts oxidation is practically unknown, but in course of time (20 to 30 years) the wire becomes very brittle and breakages result. Where the air is laden with fumes from chemical works the wire, of course, decays much more rapidly.

Yet another cause of trouble is the accumulations of snow and ice which adhere to the wires, thereby very greatly increasing the stress upon them. It is, however, only in acute cases that the wires are broken, but it is often necessary to cut and regulate them when the snow and ice have disappeared.

Kinks in the wire, due to careless handling in erection, and flaws or defects in manufacture may produce fractures, but these causes do not often operate owing to the efficiency with which the work is carried out and the care with which the various tests are made at the manufactory before the wire is accepted.

If the fallen wire rests upon dry ground the resulting earth may be slight, but, usually, the line is to almost full earth and frequently in falling it makes contact with other wires below it.

A slight fault, *i. e.* defective continuity, may be produced by an unsoldered, or badly-soldered, joint—the former often resulting from the omission to make good after a temporary repair.

In every case dealt with so far, attention has been directed to the line itself, but, in addition, there are the pole test boxes, ordinary test boxes, lightning protectors and fuses *en route*. Total and partial disconnections may be caused by broken or loose connections at any of these points. Earths are frequently found in the protectors, especially after thunderstorms. Again the leaders may be defective, but the possible causes are so many, and the actual number of faults so small, that a catalogue of all the ills to which a line is subject is quite unnecessary.

As regards underground wires, the section dealing with these wires in Chapter XXII needs but little addition. With G.P. covered wires the insulation perishes in course of time, so producing earth faults and contacts, whilst the fracture of the conductors is usually due to nicking the wire during jointing. It may be added that percha is highly inflammable, hence a route may be broken down by a fire in a street box, due to the overturning, or careless use of a lamp. Similarly a fire built over a box has been known to melt the G.P. and so put the whole of the wires in contact.

With air space cables the chief danger is from moisture entering the cable due to defective plumber's joints or the sheathing being pierced by picks or wedges when taking up the footway. Faults are extremely rare, but, when they do occur, serious difficulties result owing to the large number of wires concerned. Frequently, by careful observation of the special tests, defects may be traced and removed before they have affected the working of the circuits.

PART II. THE MAKING GOOD OF FAULTY CIRCUITS, SPECIAL ARRANGEMENTS, AND EARTH CURRENTS.

Symbols used for Lines and Apparatus upon Plans.

In order to represent the various classes of apparatus in use upon the circuits, the symbols shown at the base of Fig. 356 are employed, and in the preparation of circuit plans different colours are employed as follows:—Green, Post Office apparatus; Red, apparatus in railway telegraph offices; Black, apparatus upon private wires; Black dotted, apparatus provided by a renter, but maintained by the Post Office. The lines themselves are indicated by coloured lines as under:—

UPON MAPS.

Open	lines on roads and canals . . .	Green.
,,	,, ,, railways	Red.
Covered	,, ,, roads, canals, and railways, in pipes.	Blue tint.
,,	,, ,, ,, ,, ,, ,, ,, in boxing.	Brown tint.

Upon circuit plans telegraph and telephone lines are distinguished by dotting the latter circuits.

THE "MAKING GOOD" OF FAULTY CIRCUITS.

As previously stated, it is frequently possible to "make

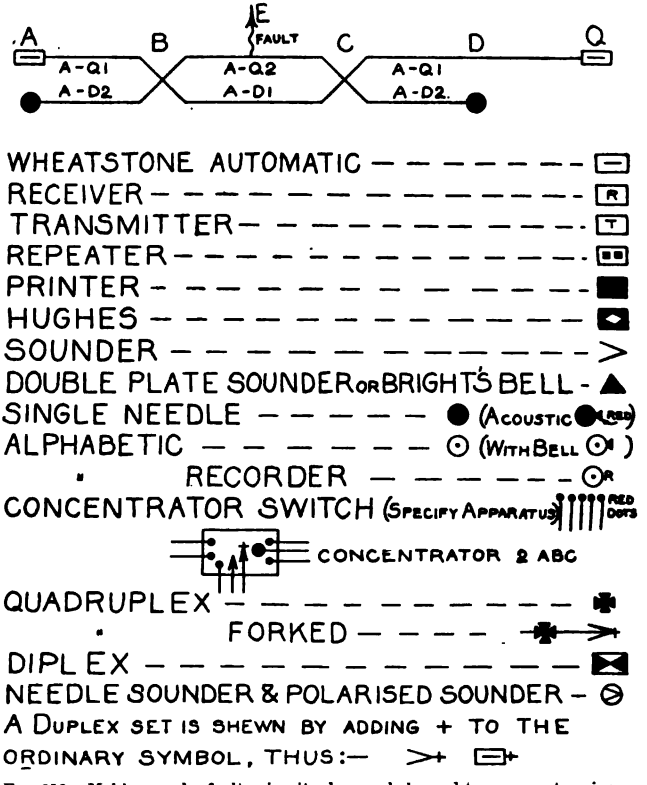


FIG. 356.—Making good a faulty circuit, also symbols used to represent various forms of apparatus.

good" a defective long circuit, by crossing the faulty section with that of a shorter circuit without seriously affecting the working of the latter. Such a case is illustrated in Fig. 356, where the lines between *B* and *C* have been crossed so as to make A-Q_1 good by throwing the fault

on to the short A-D_2 circuit. Crosses at the test boxes at B and C would be made in the manner previously described (see Fig. 312).

One good circuit may frequently be formed from two defective ones by the insertion of suitable crosses. Such a case is shown in Fig. 357, where No. 1 wire has been made good with the B-C length of No. 2. There is some advantage in throwing both faults on to No. 2, and putting the

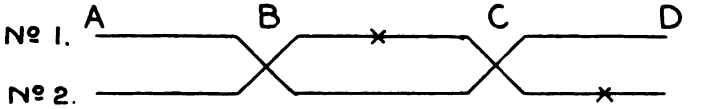


FIG. 357.—Making one good circuit from two faulty ends.

wire through, since in this way the faults may be kept under observation.

As an example of a case which may arise in practice, suppose that a London-Belfast wire, relayed at Preston and passing through Carlisle, is faulty between Stafford and Preston, whilst a London-Glasgow wire (going *viâ* Leeds)

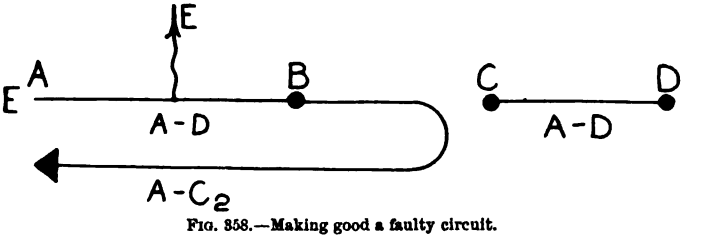


FIG. 358.—Making good a faulty circuit.

is faulty between Carlisle and Glasgow. The Belfast circuit would be made good by a cross at Carlisle, and Leeds would be asked to introduce a repeater. Both faulty sections would thus be thrown on to the Glasgow wire, which would be kept under observation.

In Fig. 358 an example is given of a case in which the circuit serving A, B, C and D is faulty between A and B. It is assumed that C is an office where testing facilities are provided, and that a wire A-C_2 is available for crossing purposes. By terminating the C D section at C and form-

ing an *A-B* circuit as indicated all the offices are provided for, but re-transmission at *C* is rendered necessary.

The A-D_3 news wire serving *B*, *C*, and *D* is shown faulty between *B* and *C* (Fig. 359), but has been made good with A-D_2, which, however, does not pass through *B* and *C*. The only change which requires comment is that the apparatus at *A* requires to be made intermediate, the *C* and *D* terminals being joined to A-D_2 and A-D_3 respectively. If secondary cell working is in vogue at *A* a special set would be used, and the short line joined to A-D_3, the set being reversed with the peg-switch.

The same result could be obtained by forking the circuits at *A*, but the method indicated is to be preferred when an intermediate or special set is available.

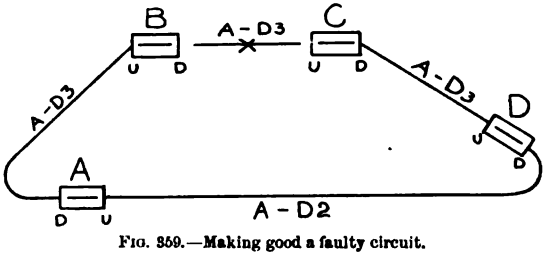


FIG. 359.—Making good a faulty circuit.

THE FORMATION OF SPECIAL CIRCUITS.

It is, of course, quite impracticable to provide each office with sufficient circuits to deal with every emergency which may arise. There are, however, a number of reserve wires which may be used for special purposes, such as race meetings, speeches, cricket and football matches, etc., and, by suitably manipulating the various circuits, almost any emergency may be provided for. In forming these circuits the guiding principles are to produce the minimum amount of disturbance to the ordinary traffic arrangements, and to use open wires upon all long circuits. The work demands a knowledge of the routes of the various wires, but this is a part of the education of every testing officer. If the record of the testing sections of each wire (see page 609) is consulted, even this knowledge is scarcely essential.

It frequently happens that only one wire passes through

an office where special work is to be dealt with, and that this particular wire cannot possibly be given up. In such a case a wire can usually be found to make good the circuit required. For instance, A-Q_1 passing through B, C, and D can be made available by crossing it with A-D_1 at A and D. The number of wires may be doubled by terminating both sides of a through wire and doubling it back at the nearest testing point where a wire is available for the purpose. These considerations will be perfectly obvious, and as the conditions to be met vary with the circuits and offices concerned, there is no advantage in illustrating specific cases. The guiding principles have been stated, and local illustrations may readily be supplied by the reader.

The battery power requisite to work the circuits is found as described in Chapter II, but it may be convenient to summarize a few useful points.

I. The per mileage resistance of an iron wire = $\frac{5328}{\text{weight per mile.}}$

II. The per mileage resistance of a copper wire = $\frac{878{\cdot}2}{\text{weight per mile.}}$

III. (*a*) Where secondary cells are used, the E.M.F. required is the nearest value in excess of that obtained by multiplying the required current in amperes by the *total* resistance of the circuit (the resistance of one lamp resistance or metal-cased resistance coil, as the case may be, must be added).

(*b*) Where primary batteries are used the number of cells required may be found thus:—

1. Leclanché cells divide the resistance of the circuit by 73 if 14 m.a. and by 50 if 20 m.a. required.
2. Daniell cells divide the resistance of the circuit by 65 if 14 m.a., and by 44 if 20 m.a. required.
3. Bichromate cells divide the resistance of the circuit by 126 if 14 m.a., and by 87 if 20 m.a. required.

The term "resistance of the circuit" in *b* 1, 2, and 3 includes the resistances of the line and apparatus, but not

the internal resistance of the battery, which is taken account of in the rules given.

IV. Covered wire should be avoided upon all long circuits owing to the reduced speed of working which it entails. With submarine cable circuits the repeater should be placed as near to the cable as possible (see page 518).

The only point which remains for comment is that occasionally an emergency arises and sufficient battery power is not available at a small office for working over a long specially formed circuit. This case may usually be met by interpolating a repeater at the nearest large office.

Earth Currents.

Two similar metallic plates immersed in two different electrolytes, separated by a porous partition, will form a voltaic couple, and therefore generate a current. There is no doubt that a slight current is produced by the two earth plates at the ends of a telegraph circuit, but this effect is of so minute a character that its effect upon the circuit may be ignored. There are also stray currents which are produced by leakage from the uninsulated return conductor (the bonded rails) of electric tramway systems. Since the difference of potential between any two points upon the system is limited to 7 volts under the Board of Trade regulations, but little trouble is experienced on this account. There are cases, however, in which local circuits having the same general direction as the tramway have been seriously affected. The remedy is to increase the resistance of the circuit by inserting a resistance coil and to correspondingly augment the battery power. As the current due to a given difference of potential is inversely proportional to the resistance, it will be obvious that the disturbing current may be reduced to negligible dimensions. It may be added that the leakage current varies from time to time, and that therefore an opposing battery cannot be inserted in the line so as to balance it.

It is found that different parts of the earth are frequently at different potentials, and that consequently "earth currents," as they are termed, flow over the circuits between the various points. In the case of very long submarine cables these currents are of sufficient magnitude to make

direct working quite impracticable. For this, and other important reasons, condensers are inserted at either end of the circuit, thus preventing the passage of a steady current through the cable. Long land lines and short submarine cables are normally unaffected by earth currents and provision against them is unnecessary.

The precise cause of earth currents has yet to be discovered.* There is, however, no doubt that they are always in evidence during periods of "magnetic" storm, *i. e.* during periods in which the declination, horizontal force and vertical force show considerable and irregular variations. When the aurora, observed chiefly in the Arctic regions, is of a rapidly-varying character magnetic storms and earth currents are invariably observed. The association of sun-spots with periods of magnetic storm has been suggested, but evidence shows that several specially large sun-spots have been unaccompanied by magnetic storms. Again, there is no evidence of any connection with earthquakes or other internal troubles of the earth itself.

As none of the theories which have been given altogether fit the observed phenomena the true cause is, at present, quite an open question.

Generally speaking, lines running N.E. and S.W. are most frequently affected, whilst those running N.W. and S.E. are seldom disturbed. A very severe magnetic storm occurred on November 1, 1903, and it was accompanied by unusually large earth currents. In England, the circuits were affected from 7.0 a.m. to 8.0 p.m., and for some hours the service was completely disorganized. Earth currents up to 60 m.a. were observed, whilst the direction and value varied from time to time. A similar state of affairs occurred in France, and Paris was unable to communicate with the greater number of French towns, and was also cut off from communication with America, Spain, Portugal, Italy, Algeria, Tunis, and many other places. Communication was re-established on the French lines at 4.40 p.m., but was interrupted at about 5.30 for a short time. Working on the London-Paris telegraph cable was also disorganized, but the Post Office submarine cable to Germany was less affected,

* See *Electrician*, November 6, 1903, page 95, "The Magnetic Storm." The present account is taken very largely from this article.

although there was considerable trouble on the land lines serving it. From New York it was reported that a bright aurora was visible on the date in question—as was also the case in some parts of these islands—and that earth current disturbances were felt in all directions, in some instances causing a total cessation of telegraph business. According to one New York correspondent a voltage of 675 was observed.

The long submarine cables were less affected than the land lines, and those upon which condensers and siphon-recorders are employed were hardly disturbed at all. Where Morse working was used, very considerable difficulty was occasioned.

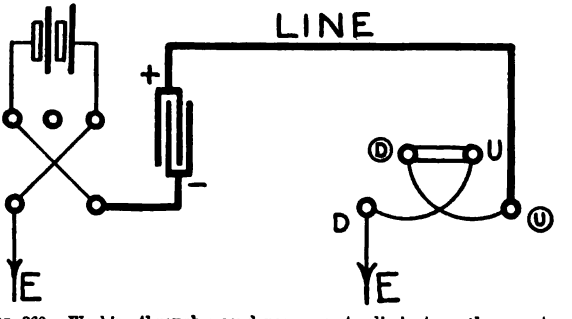


FIG. 360.—Working through a condenser so as to eliminate earth currents.

The remedies against earth currents consist in the use of a metallic circuit, or in the interpolation of condensers. The former remedy is, of course, a complete one so far as the disturbances are concerned, but it reduces the number of circuits by half. It is, moreover, impossible to carry out where secondary cell working is employed owing to the earth connections upon the batteries. In an earlier type of secondary cell installation "looping" mains were provided for this purpose, but the system cannot be worked between two offices each having secondary cells, and it was therefore abandoned in the later system.

The second remedy (the insertion of a condenser in the line) is illustrated in Fig. 360. Both galvanometers, the relay at the sending end and the key at the receiving end, have been omitted in order to simplify the diagram. The

relay must be set neutral, since a momentary current flows only when the position of the key is changed. Assuming that this has been done, and that the tongue of the relay is resting upon the left side, the depression of the key causes a current to flow through the line and relay (*U*-circle to *D*) until the charge of the condenser is reversed. The current then ceases, but it has already moved the tongue of the relay over to *M*, and as the relay is set neutral the mark continues until the key is released. When this occurs a momentary spacing current results which ends the mark. The circuit can thus be worked with but little trouble. As, however, the condenser prevents the passage of a continuous current no effect is produced either by a steady or by a slowly varying earth current.

For many years it has been common practice to insert condensers in the lines at relay stations during the prevalence of earth currents, and no difficulty is ordinarily experienced. In slight cases it is frequently only necessary to raise the resistance in the rheostat of the shunted condenser upon Wheatstone circuits. It may perhaps be noted that a bridge duplex circuit would be less affected than a differentially worked one, on account of the relatively high resistance and smaller portion of the received current which flows through the relay.

PART III. THE WHEATSTONE BRIDGE AND ITS USES.

WHEATSTONE BRIDGE.

PRINCIPLE.

The arrangement termed a Wheatstone Bridge comprises three sets of resistance coils, a battery, and a galvanometer. With the aid of this apparatus the resistance of any line, set of apparatus, or system of conductors, can readily be measured. The three resistances are usually included in a single box, and the term Wheatstone Bridge is frequently employed to denote this piece of apparatus rather than the arrangement as a whole.

The three known resistances are joined up with the resistance to be measured and the battery and galvanometer

as shown in Fig. 361. The values of these resistances are then altered until no deflection is observed upon the galvanometer. When this is the case the products of the resistances of the opposite sides are equal. In the case illustrated :—$160 \times 20 = 40 \times 80$.

It will be shown by numerical examples that when the products of the opposite sides are equal there is no current flowing through the galvanometer, and it will then be shown that when the products are unequal a current will flow.

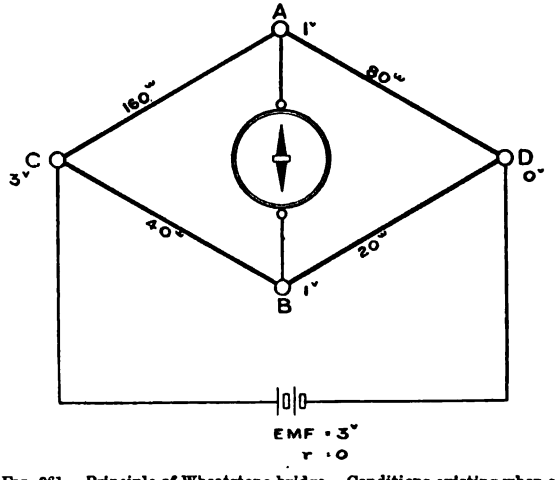


FIG. 361.—Principle of Wheatstone bridge. Conditions existing when a balance has been obtained.

The resistance of the battery is assumed to be negligible in order to facilitate the arithmetical work. The difference of potential between C and D is therefore the same as the E.M.F. of the battery, viz. 3 volts. The galvanometer may for the present be entirely ignored.

$$\text{Current through } C\ A\ D = \frac{3}{160 + 80} = \cdot 0125 \text{ ampere.}$$

$$\text{Current through } C\ B\ D = \frac{3}{40 + 20} = \cdot 05 \text{ ampere.}$$

Difference of potential between C and $A = 160 \times \cdot0125.$
$= 2$ volts.
,, ,, C and $B = 40 \times \cdot05.$
$= 2$ volts.
,, ,, A and $D = 80 \times \cdot0125.$
$= 1$ volt.
,, ,, B and $D = 20 \times \cdot05.$
$= 1$ volt.

From this it is apparent that A and B are at the same

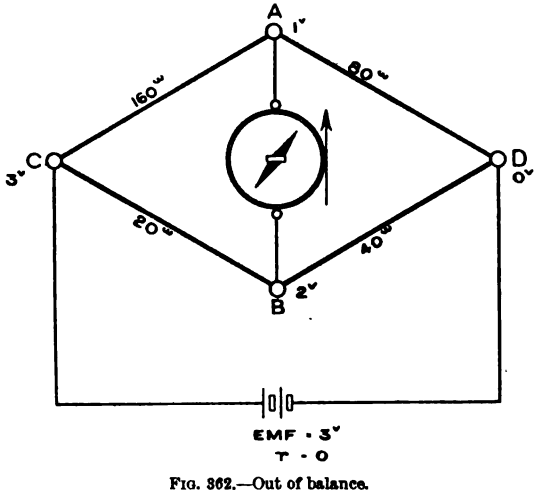


FIG. 362.—Out of balance.

potentials, and therefore a galvanometer connected between them will not be affected. The negative pole of the battery has been considered to be at zero potential, thus giving the positive a potential of 3 volts. At A and B the potential is 1 volt above zero (D), since 2 volts is lost through C A and C B.

In Fig. 362 the two lower resistances have been reversed, thus leaving the values of the currents circulating in the upper and lower pair of resistances unchanged. Again ignoring the presence of the galvanometer the following results are obtained :—

Difference of potential between C and A $= 160 \times \cdot0125.$
$= 2$ volts.
" " C and B $= 20 \times \cdot05.$
$= 1$ volt.
" " A and D $= 80 \times \cdot0125.$
$= 1$ volt.
" " B and D $= 40 \times \cdot05.$
$= 2$ volts.

Upon the same argument as before, the potential at B is 2 volts whilst that at A is 1 volt. There is therefore a difference of potential between A and B, and a galvanometer connected between them would be deflected.

It has now been shown that in a particular case the galvanometer is undeflected when the products of the opposite sides are equal, and, in another, that it is deflected when they are unequal. If any other cases are taken the same results will be obtained.

The underlying principle of the proof which has been given may be stated in the following form:—

1. When the potential difference between C and A bears the same ratio to that between A and D as the potential difference between C and B bears to that between B and D the points A and D are at the same potential.

2. Since the current in $C\,A$ is the same as that in $A\,D$ and the current in $C\,B$ is equal to that in $B\,D$, the resistances $C\,A$ and $A\,D$ are proportional to the potential differences. Similar remarks apply to $C\,B$ and $B\,D$.

From these statements it follows that when the points A and B are at the same potential,

$$C\,A : A\,D :: C\,B : B\,D.$$

In the case of Fig. 361, $160 : 80 :: 40 : 20$.

P.O. Form of Wheatstone Bridge.

The three known variable resistances and the unknown resistance are depicted in Fig. 363, but in this case the resistances of the coils have been given the values which are employed in the Post Office pattern of Wheatstone Bridge. The two sets of three coils (10Ω, 100Ω, and 1000Ω) are termed the proportionals. By means of the 16 coils which compose R any resistance from 1Ω to 11,110Ω by

gradations of 1^{ω} may be inserted. The resistance to be measured is connected between A and D and forms the fourth resistance. Two keys are also inserted, one in the battery and one in the galvanometer circuit, but the explanation of their purpose will be deferred to a later stage. When a balance has been obtained, *i. e.* when the resistances in a, b and R have been altered so that no deflection is obtained when the battery and galvanometer

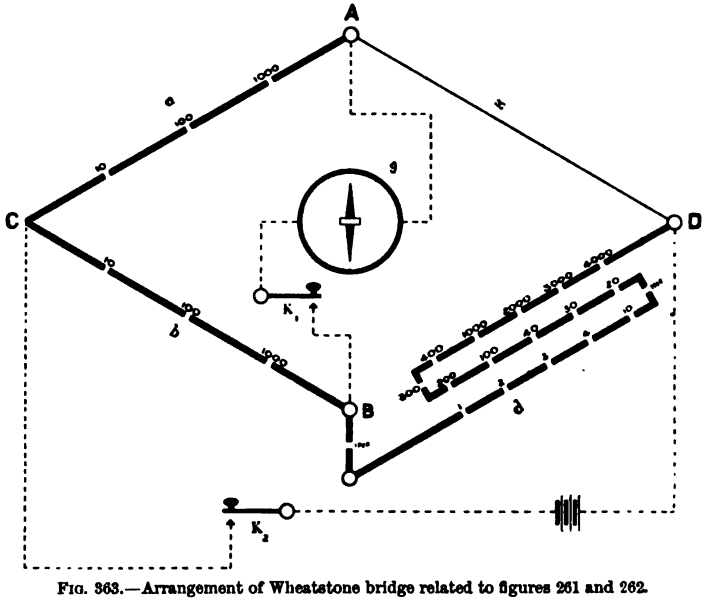


FIG. 363.—Arrangement of Wheatstone bridge related to figures 261 and 262.

are joined up by means of the keys, the products of the resistances of the opposite sides of the bridge are equal—

$$a \times R = b \times x.$$

$$x = \frac{a}{b} \times R.$$

If a and b are equal the resistance in R is equal to the unknown resistance x. If a is 1000 and b is 10 then the unknown resistance is 100 times that of R. The highest resistance which such a bridge can measure is

therefore $100 \times 11{,}110^{\omega} = 1{\cdot}111$ megohms. The ratio of a to b may be made 1, 10, 100, $\frac{1}{10}$, or $\frac{1}{100}$, thus theoretically providing for the measurement of any resistance from $\frac{1}{100}^{\omega}$ to 1·111 megohms. Since all these ratios are multiples or sub-multiples of 10 the value of any resistance tested may be written down without calculation. For instance, if a is 100, b is 1000, and R is 1536, when a balance is obtained the resistance tested is $153{\cdot}6^{\omega}$.

Referring to Fig. 362 it will be seen that when the resistance in $B\,D$ is greater than the value required to

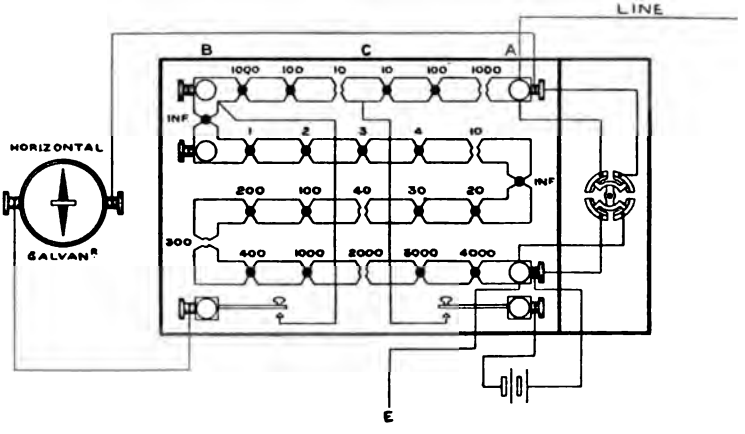


FIG. 364.—Actual arrangement of a Wheatstone bridge of the P. O. pattern.

obtain a balance (viz. 10^{ω}) a current flows from B to A. If now $B\,D$ were made nothing the potential of B would be that of the negative pole of the battery, and a current would therefore flow from A to B. Thus the direction of the deflection at once indicates whether the resistance inserted in $B\,D$ is greater or less than that required to produce a balance.

The general appearance of the bridge and its connections are shown in Figs. 364 and 365.

PRACTICAL USE OF THE BRIDGE.

The battery power required when using the bridge in conjunction with the horizontal galvanometer (Fig. 28) is

usually about 20 Large Daniell cells. For testing insulation resistances 30 and 40 cells may be used when the proportionals bear the ratio of 10 and 100 respectively. For measuring very low resistances but 10 cells should be used. It may, however, be pointed out that a Wheatstone Bridge is not a satisfactory instrument for measuring resistances greatly below one ohm, owing to the resistance which is necessarily introduced in the connections which have to be made.

FIG. 365.—View of a Wheatstone bridge.

In measuring a resistance by means of the Wheatstone Bridge the following rules should be observed :—

1. The values of the resistance inserted in the proportionals should be as near to that of the resistance to be measured as is possible.
2. The right-hand (battery) key should be depressed before the left (galvanometer) key.
3. The battery should be applied for the shortest possible time.
4. In the case of measurements of resistances containing

an E.M.F. the resistance should be measured with both directions of current.

These rules are obtained by mathematical investigations, but they may be verified by taking a few simple numerical cases. For instance, let the rheostat arm have a resistance of 101$^{\omega}$ with 100$^{\omega}$ connected as the unknown resistance. It will be found that with a given E.M.F. the difference of potentiality across the galvanometer is much greater with the two 100$^{\omega}$ proportionals than with the two 10$^{\omega}$s or the two 1000$^{\omega}$s. Similarly it may be shown that the galvanometer will be undeflected if the proportionals have no resistance, even when the rheostat arm has no resistance inserted whilst the fourth arm is disconnected.

Let it be known that the resistance to be measured is between 500$^{\omega}$ and 800$^{\omega}$. From Rule 1 the values of the proportionals should be 1000 each in preference to 10 : 10 or 100 : 100. In the present case it will be assumed that the resistance to be tested is entirely free from E.M.F. Rules 2 and 3 should be observed in the case of each measurement.

Firstly, the infinity plug should be taken out and the keys depressed. If no deflection results either the battery is disconnected or the resistance to be measured is disconnected. A deflection proves that the value of the resistance is less than infinity. The direction of the deflection (usually arranged to be to the right) indicates that the resistance inserted in the box is too great.

The following operations would result—

Resistance unplugged.	Deflection towards.	Unknown resistance is.
Infinity	Right	Between 0 and infinity.
1000 ohms	Right	Between 0 and 1000 ohms.
400 ,,	Left	Between 400 and 1000 ,,
600 ,,	Left	Between 600 and 1000 ,,
650 ,,	Right	Between 650 and 600 ,,
630 ,,	Left	Between 630 and 650 ,,
640 ,,	Left	Between 640 and 650 ,,
645 ,,	Right	Between 640 and 645 ,,
643 ,,	Right	Between 640 and 643 ,,
642 ,,	Nil	642 ohms.

Measurement of Resistances having Capacity, Self-Inductance, or an E.M.F.

The battery and galvanometer keys greatly facilitate the measurement of resistances having capacity or self-inductance. The coils of the bridge are double-wound so as to have the minimum amount of self-inductance. Reference to Fig. 363 will show that when the resistance unplugged in *B D* is too little the galvanometer deflects to the right, whilst too large a resistance produces a deflection to the left. If an electromagnet having a resistance of 100$^{\omega}$ is placed in the fourth arm of the bridge with 100$^{\omega}$ inserted in each of the other arms, a perfect balance will be obtained when the current has attained its steady value. By depressing the battery key before the galvanometer key ample time will have been allowed for the current to rise to its full value in the electromagnet and the galvanometer will be unaffected. If, however, the galvanometer key is depressed before the battery key, the galvanometer will be momentarily deflected owing to the E.M.F. of self-induction opposing the current. The direction of the kick will be such as to indicate that too little resistance has been unplugged in the box.

When the resistance to be measured possesses capacity, a rush of current takes place into the cable or condenser as the case may be. This upsets the balance in the opposite direction to self-induction, and the deflection therefore is such as to indicate that too much resistance has been inserted. By depressing the battery key before the galvanometer key the current attains its Ohm's law value before the galvanometer is applied, and therefore a perfect balance is obtained when the four resistances bear the correct relations to each other.

Having obtained a balance it may be ascertained whether the circuit possesses capacity or self-inductance by depressing the galvanometer key first. Where both are present this test is inconclusive, since either may predominate or they may be balanced.

When the circuit under test has an E.M.F. in it a deflection will be observed when the galvanometer key only is depressed (provided resistances are unplugged in the proportionals). The same effect may, however, be produced

by defective insulation of the testing battery, but this is readily verified by disconnecting the bridge from the line under test and leaving the earth connection. This defect is not uncommon, especially where dry cells have to be used in the open, but it may be eliminated by standing the cells upon a perfectly dry board.

Reversing Switch and the Measurement of the Resistance of Earthed Circuits.

In order to facilitate the reversal of the testing current whilst preserving the meaning of the deflection, a reversing switch is mounted upon one end of Post Office pattern bridges (compare Figs. 364 and 365). The two lower quadrants are respectively connected to the end of the proportional arm *C A* and to the end of the rheostat arm, whilst the two upper quadrants are joined to the upper parts of the terminals, the upper and lower binding screws being insulated from each other by means of a flanged ebonite tube.

When the two contact pieces occupy the positions shown in Fig. 364, the upper and lower parts of the two terminals are respectively joined together. By turning the handle through 90° the two upper and the two lower quadrants are joined, thus reversing the connections of the line and earth between *A* and the end of the rheostat arm. This reverses the direction of the testing current, but consideration will show that a deflection to the left still means that too much resistance has been inserted. If the battery itself were reversed a similar deflection would then mean that too little resistance had been inserted. This would tend to confusion in making the successive tests, and therefore the connections of the line and earth are reversed instead.

It has been remarked that slight earth currents are nearly always present upon telegraph lines, and, when measuring the conductor resistance, it is therefore necessary to take two measurements, one with each direction of current. The true resistance may then be assumed to be equal to the arithmetic mean (sum divided by 2) of the two tests. Where the earth current is such as to produce a considerable difference the geometric mean (square root

of the product) should be taken, as this is a nearer approximation. For example, let the readings obtained be 1520$^{\omega}$ and 1530$^{\omega}$, the actual resistance of the circuit is then $\frac{1520 + 1530}{2} = 1525^{\omega}$.

In this case the geometric mean, *i.e.* $\sqrt{1520 \times 1530}$, is practically the same. Had the two tests given 50$^{\omega}$ and 150$^{\omega}$ the results obtained would differ considerably, the arithmetic mean being 100$^{\omega}$ and the geometric mean ($\sqrt{50 \times 150}$) being 86·6$^{\omega}$, which is very approximately correct. To summarize, it may be said that where the two tests differ but little the arithmetic mean is sufficiently correct, whilst in cases of considerable percentage difference the results so obtained are too large and the geometric means should be taken.

Another way of dealing with earth currents is to balance to a "false zero." The zero of the galvanometer is considered to be at the value of the deflection obtained when the galvanometer key only is down. It must, however, be remembered that every time an alteration is made in the resistance in the box this deflection is altered, and therefore the process is somewhat tedious. A balance is obtained when the deflection obtained by depressing both keys is equal to that produced by the galvanometer key alone. Yet another method consists in bringing the needle to zero by means of a magnet, but the same objection applies as to the previous method, viz. that every alteration in the resistance entails a readjustment of the magnet. It may, however, be added that the operation of taking the tests is scarcely as troublesome as would be expected.

Individual Resistance of a Number of Circuits between the same two Points.

It is frequently necessary to accurately measure the resistance of several wires between two particular points. The use of an earth connection for this purpose is not entirely satisfactory, since slight earth currents are always present and the resistance of the earth connection itself is a somewhat uncertain quantity. Moreover, electric tramway systems have been rapidly developed, and the leakage

currents vary in value from moment to moment, and thus render the taking of an accurate balance most difficult—if not actually impossible. In such cases, where three or more wires connect the two points in question, the individual resistances of the wires can readily be obtained. At the distant end, the wires are all bunched together, and the resistances offered by various combinations are measured.

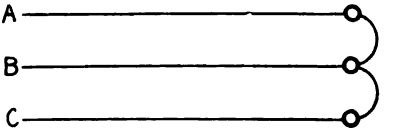


FIG. 366.—Wires looped for the individual conductor resistance tests.

Let *A*, *B* and *C* (Fig. 366) represent three wires, the individual resistances of which are required. The following tests are made :—

1. The resistance of *A* and *B* is measured
2. „ „ *B* and *C* „
3. „ „ *A* and *C* „

The results of the first two tests added together give the resistance of *A*, the resistance of *C*, and twice the resistance of *B*. If the result of the third test (*A* and *C*) is now deducted the remainder is equal to twice the resistance of *B*. Dividing this by 2 gives the resistance of *B* alone, whence the resistances of *A* and *C* are at once evident.

As an example let the results of the tests be as under :—

	(1) 231Ω	(2) 255Ω	(3) 234Ω
A and *B*		= 231	
B and *C*		= 255	
A and *C* and twice *B*		= 486	
A and *C*		= 234	
Twice *B*		= 252	
B		= 126Ω	
∴ *A*	= 231 − 126	= 105Ω	
and *C*	= 234 − 105	= 229Ω	

Had the number of wires been greater than three the same principle would be applied. Knowing *C* and measur-

ing the value of C and D would determine D. Knowing D and measuring D and E would give E and so on.

Formulæ after the fashion of that given below may be derived, but as the principle is so simple and obvious their utility is distinctly doubtful.

$$\text{Resistance of } B = \frac{(1)+(2)-(3)}{2} = \frac{(A+B)+(B+C)-(A+C)}{2}$$

Periodical Conductor Resistance Tests.

The conductor resistance of every circuit is measured once a week by means of the Wheatstone Bridge, and upon

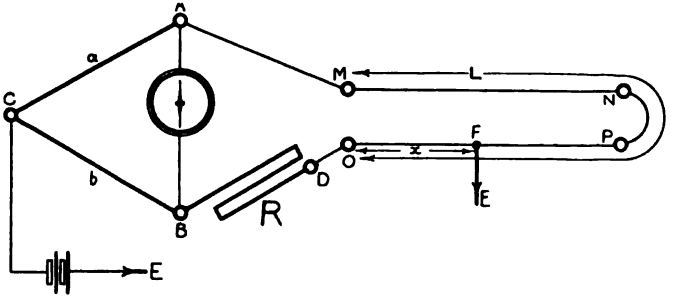


Fig. 867.—Principle of the Varley loop test for the position of an earth fault.

this morning the ordinary insulation tests are omitted. The circuits are measured in pairs and the same arrangements which are needed for the insulation readings serve for these tests. The results are valuable since, by comparing wires of the same gauge between the same points, any slight defect is apparent, whilst dry joints or loose connections are invariably advised and dealt with in the same manner as other classes of fault. Pronounced defects of this character upon aërial lines invariably cause the needle of the galvanometer to oscillate from side to side.

In the case of circuits which are earthed through 10,160$^{\omega}$ for the morning test-readings it is, of course, necessary to put the line direct to earth for the conductor resistance test.

Varley Loop Test

The exact position of an earth fault may be found by means of the Varley loop test when a perfect wire is available for the test. The resistance of the looped wires is measured in the ordinary way, and the connections are then altered to those shown in Figs. 367 and 368. In the former figure the principle of the test is indicated. It consists in throwing the rheostat arm into the circuit and, by earthing the battery, connecting it to the point at which the fault exists. When a balance is obtained the product of $C\ A$ and $(B\ D+O\ F)$ is equal to the product of $C\ B$ and $M\ N\ P\ F$. Assuming that $C\ A=C\ B$ then the resistance (x) of $O\ F$ is obtained

$$x=\frac{L-R}{2}.$$

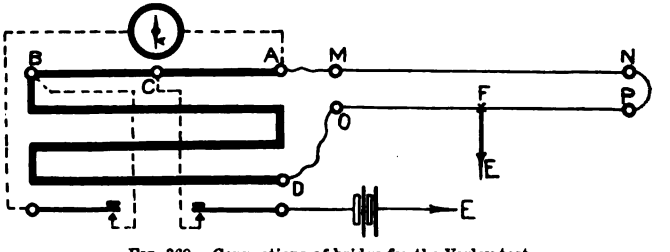


Fig. 368.—Connections of bridge for the Varley test.

where L is the resistance of the loop obtained by the first test and R is the resistance unplugged in $B\ D$ to obtain a balance.

For example, let $L=800$ and $R=400$, then $x=\frac{800-400}{2}$ $=200$ ", which is the resistance of the line up to the point at which the fault exists.

Where a and b are unequal $a\ (R+x)=b\ (L-x)$

whence $$x=\frac{b\ L-a\ R}{a+b}.$$

It will be observed that the resistance of the fault does not enter into the calculation at all, its only effect being to reduce the difference of potential applied between C and F.

The result of the test gives the resistance of the faulty

wire between the testing office and the point at which the fault occurs, and, with the aid of the records of conductor resistance tests, the distance of the fault in miles from the testing office may readily be obtained. In the case of underground circuits the position may be obtained with very considerable accuracy since, owing to the constancy of the temperature, the resistances of the wires do not vary.

The test is a very accurate one when the resistance of the fault is low and the insulation is high. If the fault is a slight one and approximates to the insulation of the rest of the circuit the results obtained are valueless. The whole principle lies in the assumption that there is one definite fault upon an otherwise perfectly insulated pair of wires.

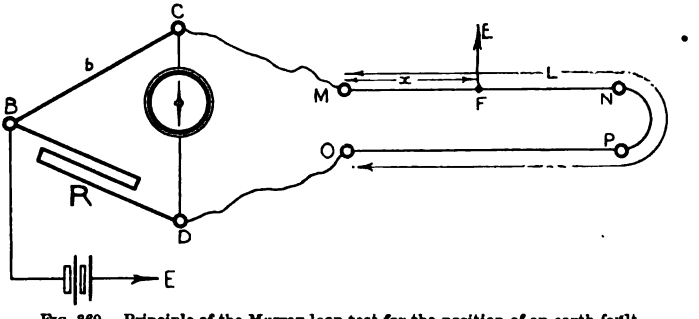


FIG. 369.—Principle of the Murray loop test for the position of an earth fault.

The position of an earth fault upon one of the wires in a lead-covered cable may be localized by this method, but as the resistances of the sections tested are usually low the ratio arms are made unequal, and care is taken to observe the resistance of the leads employed.

MURRAY LOOP TEST.

The Murray loop test may be used in precisely the same circumstances and, under some conditions, is to be preferred. The arrangement is illustrated in Figs. 369 and 370, from which it will be seen that the four arms of the bridge are formed by BC, BD, MF, and $FNPO$. When a balance is obtained $BC \times OPNF = BD \times MF$, *i. e.*

$$b\,(L-x)=R\,x$$

whence $$x=\frac{b\,L}{R+b}$$

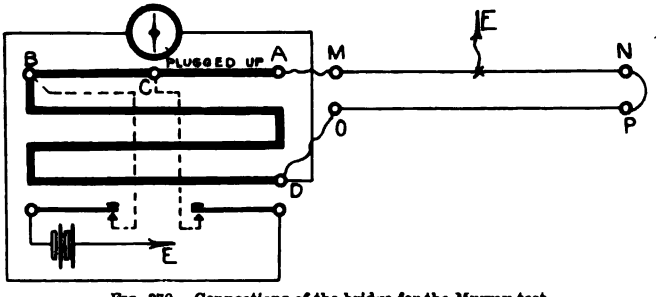


FIG. 370.—Connections of the bridge for the Murray test.

where x = resistance of $M\,F$
b = $B\,C$
R = $B\,D$
L = resistance of the loop $M\,N\,P\,O$ obtained as in the Varley test.

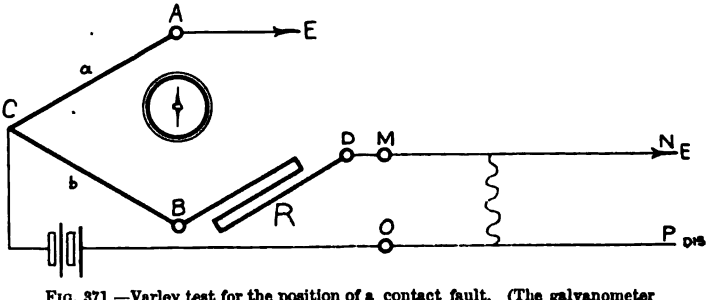


FIG. 371.—Varley test for the position of a contact fault. (The galvanometer is connected between *A* and *B*.)

As an example, let the resistance of the loop = 100 ω, b = 100 ω and R = 536 ω; then $x=\frac{100\times100}{536+100}=15{\cdot}7$ ω approx.

Similar remarks as regards high resistance faults upon circuits having a low insulation resistance apply to this as to the Varley test.

Tests for the Position of a Contact.

The position of a contact may be obtained as indicated in Fig. 371 (compare with Fig. 367), but where possible it is preferable to avoid the use of earth by employing a

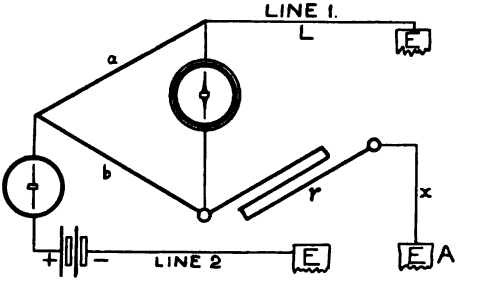


Fig. 372.—Pomeroy's test for the resistance of an earth; first reading.

third wire. The Murray test may be applied to this case quite readily, but it is believed that the principle is now sufficiently apparent.

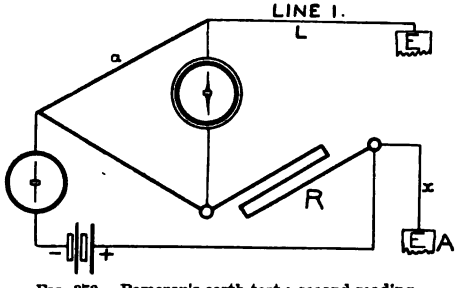


Fig. 373.—Pomeroy's earth test; second reading.

Pomeroy's Method of Testing Earths.

It is frequently necessary to obtain the resistance of an earth connection, and, by making the two tests shown in Figs. 372 and 373, this may be accomplished with a fair amount of accuracy. Two lines connected to two independent earths are required for the tests and are joined up as

shown. It is necessary that the value of the current passing at the earth plate should be approximately equal in both cases, and the battery power required for the second test should therefore be increased accordingly. This may best be judged by inserting a detector in series with the battery as indicated. The battery connections are reversed in the second test, so that the direction of the current from the plate at A may be the same in both tests (L includes the resistance of the earth upon Line 1).

1st test. $a\,(r + x) = b\,L$

2nd test. $a\,R = b\,(L + x)$

whence $$x = \frac{a\,(R - r)}{a + b}$$

or when the proportionals a and b are equal:—

$$x = \frac{R - r}{2}$$

that is half the difference between the two resistances required to produce a balance.

PART IV. INSULATION TESTING SET AND THE *Q* AND *I* DETECTOR.

Insulation Testing Set

The highest resistance which can be measured by means of a Wheatstone Bridge of the Post Office pattern is slightly over one megohm. This limit is far too low for testing the insulation of air space cables, and to meet this requirement the "insulation testing set" illustrated in Fig. 374 was devised. It consists of a horizontal galvanometer of the same general form as that illustrated in Fig 28, but wound to a resistance of 25,000Ω. The scale is divided into equal divisions, and the skew scale principle adopted in order to increase the range. The battery power consists of six 50-cell dry batteries contained within six boxes. These cells are of a very small size, but are quite adequate for this purpose, since the currents needed are usually very small fractions of one milliampere. The E.M.F. of the battery is roughly 450 volts.

Each box is provided with four terminals, so that 1, 10, or the whole 50 cells, may be connected up, and a 1000$^{\omega}$ resistance coil is also included so that the possibility of a short circuit may be avoided. The boxes should stand upon a thick sheet of gutta-percha, so as to ensure satisfactory insulation. The battery leads are connected to the battery terminals by means of clips having insulated handles, thus avoiding the possibility of electric shocks which might result from handling the terminals.

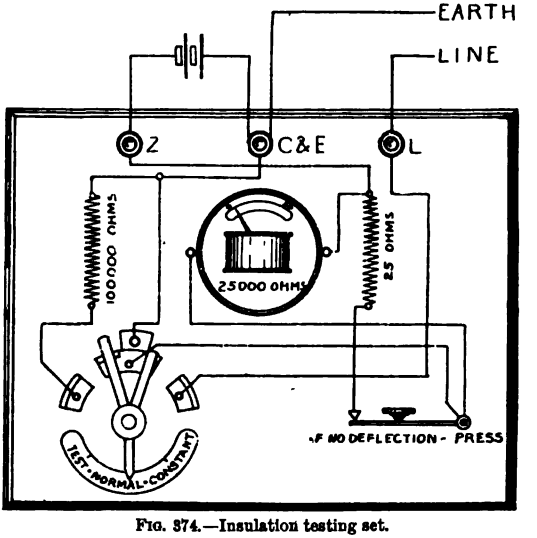


FIG. 374.—Insulation testing set.

The switch is first turned to the "constant" position, and the deflection observed. It will be seen that the battery is connected in series through a resistance of 100,000$^{\omega}$, and that the galvanometer is shunted $\frac{1}{1000}$. With these conditions the constant obtained is usually about 15°. With the galvanometer unshunted the same battery would produce a deflection of 15° through 100,000$^{\omega}$ × 1000 = 100 megohms. The degrees may be assumed to be roughly proportional to the current, and therefore the resistance corresponding to any deflection is, assuming the constant to be 15° :—

$$\frac{1500}{\text{Deflection}} \text{megohms unshunted}$$

and $$\frac{1{\cdot}5}{\text{Deflection}} \text{ megohms when shunted } \tfrac{1}{1000}*$$

The switch is turned to "test," and one minute later the key is pressed, thus removing the shunt from the galvanometer, and the deflection observed. When the deflection is beyond the scale with the key depressed and is imperceptible with the $\frac{1}{1000}$ shunt in, the battery power is reduced sufficiently to obtain a reading, and the constant with the reduced power noted or calculated as being reduced in the ratio of the total number of cells to the number used for the test. In order to discharge the cable an earth-connected stud, which is passed over by the longer end of the contact spring in its passage from "test" to "normal" position, has been added.

When testing the insulation of unscreened wires contained in a lead-covered cable difficulty frequently arises owing to the inductive action of the working circuits in that cable. Since such wires are invariably arranged in twisted pairs a differentially wound galvanometer (12,500$^{\omega}$ per coil) is employed, one coil being connected to the battery and wire under test, whilst the other coil is connected to the companion wire and earth through a resistance equal to that of the testing battery which (with the 1000$^{\omega}$ coils in the boxes) will be 1100$^{\omega}$ per 50 cells. In this way, the currents induced upon the wire under test are exactly balanced by those induced upon the companion wire of the pair since the two coils are joined up so as to oppose. Both wires are, of course, disconnected for the test.

* The accurate formula is :—

$$x = \frac{d_1}{d_2}\left\{\frac{G+S}{S}(R+B)+G\right\}-(G+B)$$

where d_1 is the constant,
d_2 is the observed deflection,
G, S, R and B are respectively the resistances of the galvanometer, shunt, resistance coil and battery.

In taking the insulation resistance of cables all quantities save the multiplying power and the resistance coil may be neglected.

ELECTRIFICATION.

If an earthed battery and galvanometer are connected to a gutta-percha insulated wire disconnected at the further end (as shown in Fig. 375) it will be observed that the deflection produced continuously falls, thus indicating that the insulation steadily improves under the prolonged application of the battery. This phenomenon is usually, if not invariably, termed "electrification," but "absorption" or "dielectric polarization" would more accurately describe the effect. It is practically certain that the true insulation resistance does improve and that the minute leakage current passing through the percha is constant. When the E.M.F. is first applied to the cable there is a heavy rush of current of short duration to charge it, and it seems probable that

FIG. 375.—Illustrates electrification phenomenon.

there is some sort of yielding or soaking in of the charge and that this alone is responsible for the increase of the deflection above that due to the true leakage current through the dielectric. If the battery is removed and the earthed galvanometer connected to the cable a steadily diminishing current is observed, thus indicating the exudation of this extra charge. Another explanation lies in a possible polarization effect in the dielectric.

Precisely the same effect is observed with condensers, the phenomenon being more marked with those having paraffined paper, than with mica, insulation.

This effect is greater at low temperatures, but varies not only with the nature of the dielectric but with quality of material, being smaller in the best class of gutta-percha than in inferior grades. Kempe instances an experiment in which the insulation reading fell from 240 to 75 divisions in 90 minutes at 32° F., whilst at 75° F., with the same specimen, the deflection fell to but 173 in the same length of

time. With india-rubber the deflection falls much more rapidly, but with a far smaller difference between the maximum and minimum readings. With paper cables the fall is still less.

In all measurements of the insulation resistance of covered wires the reading is taken after a prescribed number of "minutes' electrification," or in other words after the testing battery has been applied for that length of time. The phenomenon is quite independent of the value of the E.M.F. and of the direction of the current, but in repeating a set of measurements care must be taken that the whole of the electricity absorbed is discharged before attempting to do so. With long lengths of cable a considerable time must be allowed, the cable meanwhile being put to earth.

One other point which should be remarked is that with a perfect core the deflection falls in a regular and steady manner, and that any irregularity is presumptive evidence of a defect in the insulation. In addition to the readings, it should always be noted whether the electrification is steady or irregular.

With comparatively short lengths of air-space cable the phenomenon is very small, and the reading taken after one minute's electrification represents very approximately the true insulation.

The Grouping of the Wires in an Air-space Cable for Insulation Tests.

The insulation of an air-space cable is of the order of from 5000 to 50,000 megohms per mile. In order to obtain readable deflections upon lengths of from 100 to 400 yards with ordinary battery powers, and also to reduce the number of tests to be made, the various conductors are grouped. It is essential that the insulation between every wire and every other wire of the cable with which it is physically possible for it to be in contact shall be proved. Therefore, no wire may be tested in the same group as its companion wire if a twin (or wires if a quadruple twin) cable, either wires of the pair on either side of it in the same layer, or any wire in either the layer directly above or below it.

Taking the case of the 74-wire cable illustrated in Fig. 376 the following groups may be formed :—

A — 39, 43, 47, 51, 55, 59, 63, 67, 71, 3, 7, 11.
B — 40, 44, 48, 52, 56, 60, 64, 68, 72, 4, 8, 12.
C — 41, 45, 49, 53, 57, 61, 65, 69, 73, 5, 9, 13.
D — 42, 46, 50, 54, 58, 62, 66, 70, 74, 6, 10, 14.
E — 15, 19, 23, 27, 31, 35, 1.
F — 16, 20, 24, 28, 32, 36, 2.
G — 17, 21, 25, 29, 33, 37.
H — 18, 22, 26, 30, 34, 38.

FIG. 376.—Arrangement of a 37-pair dry core cable.

Each group may be tested provided all the other groups are, during the test, put to earth and therefore, instead of 74 tests, but eight are needed. With a larger cable containing, say, 600 wires, the reduction in the number of tests is still more remarkable. It will be seen that the principle consists in grouping together only those wires between which it is physically impossible for a contact to occur. If group A gave an insulation resistance of 500 megohms in a length of 220 yards, the per mileage insulation resistance of the whole group would be 4000 megohms, and the average insulation of each wire 48,000 megohms per mile.

From the example which has been given, and the statement of the underlying principle, it should be possible for the reader to work out the arrangement for any other type of cable. For instance, a screened conductor cable could be tested in a single operation, since each wire is surrounded

by a copper tape. The method of carrying out such tests during the jointing of successive lengths of cable will be reverted to in Chapter XXII.

Q AND *I* DETECTOR.

As a conclusion to the present chapter it will be well to describe the "*Q* and *I* detector" which forms so important a part of the equipment of every lineman. The "*Q* and *I*" part of the title is a survival of the days when the terms "quantity" and "intensity" were in general use. The detector (Fig. 377) is provided with two windings,

FIG. 377.—*Q* and *I* detector.

having resistances of 100$^{\omega}$ ("intensity" coil), and ·2$^{\omega}$ ("quantity" coil), the latter being provided with a $\frac{1}{5}$ shunt inserted by means of the switch upon the top of the case. The needle is of the Varley induced type, but the permanent magnets are disposed in a slightly different manner in order to economize space. The central terminal is common to both coils and in a form of detector, used in connection with the Webb and Thompson railway staff system, a $\frac{1}{10}$ shunt and switch is added to the 100$^{\omega}$ coil.

The figures of merit are specified as follows:—100$^{\omega}$ coil, 9·3 m.a. should produce a deflection of from 40° to 50°; ·2$^{\omega}$ coil, 139 m.a. should produce a deflection of from 20° to

30°; $\frac{1}{5}$ shunt on ·2ω coil, the application of this shunt should cause the deflection to fall to $\frac{1}{5}$ of its amount.

The 100ω coil serves as an index to the E.M.F. of a cell, and the readings clearly indicate the differences between the E.M.F. of the various cells forming a battery. Similarly the ·2ω coil may be used to gauge the internal resistance. Each cell of a battery in good condition will give approximately the same deflection with the ·2ω coil as will the whole battery, and this is probably the test which is most frequently used. The detector is, of course, used in tracing instrument faults, in tracing a difficult fault upon an open wire, for the same purposes as the test box detector, for numbering wires, and many other special purposes too numerous to specify in detail.

CHAPTER XXI

THE CONSTRUCTION OF AERIAL LINES.

Introductory.

TELEGRAPH lines may be divided into two great classes, aërial or overground and underground lines. Open work is preferable to underground on account of its greater cheapness, accessibility, and superior electrical properties. The capacity of an underground wire is far in excess of that of an open line, and consequently the working speed of the former is considerably less than that of the latter in the case of long circuits.

Aërial lines are erected upon poles on public roads, private property, railways, and canals. If a free choice can be made the public road possesses by far the greatest advantages. The line is always readily accessible, and there is little chance of costly removals and diversions having to be made. Where the plant is placed upon private property the owner's consent must be obtained, and, if this is not hedged with impossible conditions, there is still the fact that it is within his power at any time to demand the removal of the fixtures by giving the stipulated notice. The result may be a diversion of the most costly character, or the difficulty may be met quite readily and cheaply, but the fact remains that every fixture upon private property is subject to the personal will or caprice of the property owner. Therefore every attempt is made to secure a route upon public roads before private wayleaves are considered.

Upon canals a wayleave payment has to be made, but the risk of compulsory removal is comparatively remote.

The railways, upon the other hand, have the disadvantage that the maintenance of the wires is usually in the hands

of the company's staff, so introducing a dual control. It is certainly preferable that the lines and apparatus should all be under the control of one administration. Apart from this, the railways afford excellent facilities for the erection of telegraph lines, since the banks of the railway provide such effective staying facilities. The poles may be quite short, since there are no buildings to cross; removals cannot occur as the result of external building operations, nor do the lines suffer from the proximity of growing trees. The lines are also more sheltered and less liable to damage by stone-throwing. The use of the train for inspecting lines probably leads to that duty being less efficiently performed than in the case of a road-line along which there is no means of travelling at so rapid a pace.

In large towns the erection of poles along the busiest streets is quite impracticable, and here there are two alternatives, viz. overhouse and underground. By the former term is included all cases where the wires are carried upon standards erected upon the roofs, or upon brackets fixed on the chimney-stacks or corners of the various buildings *en route*. The objections to this course are that the average roof is not constructed for the purpose, and that, sooner or later, the frequent access to the roof causes complaints which finally culminate in a request to remove the fixture. The diversion involved may be of a most costly and difficult character. Quite apart from this, there is, almost invariably, trouble in regard to roof repairs, for whatever damage occurs is, without exception, ascribed to the presence of the standard or to the necessary access to the roof obtained for the purpose of attending to faults, renewals, the erection of additional wires, removals, and repairs generally.

Underground lines possess the advantage of immunity from damage due to storms, and it is from this point of view that most of the great telegraphic centres are being linked together by underground routes. Upon the other hand, the underground route has dangers of its own, for, whenever the streets are taken up, there is the possibility of damage due to carelessness or accident. Moreover, a general fault due to the entrance of water into a cable cannot be remedied with the speed that characterizes the repair of an open line breakdown.

Where a very considerable number of wires is required an underground route is less costly than several open ones. Where iron poles are to be used the cost of the underground line becomes less than that of the open line when the number of wires exceeds about thirty.

Timber.

The supply of telegraph poles is obtained almost exclusively from Scandinavia, and the poles are cut from red fir-trees. For special purposes, such as square terminal poles, American pitch pine is also employed, but the cost is considerably greater than that of fir, owing partly to the fact that the huge demand for the latter enables the most favourable conditions for cheap transport to be met, and partly to the greater cost of the timber itself.

The use of iron poles is avoided wherever possible owing to their extreme costliness, which amounts to from four (in the case of long heavy poles) to eight (for light poles) times that of the corresponding wooden poles.

The timber selected for telegraph poles should be quite sound and hard grown (that is with the annular rings closely pitched), straight, and free from large or dead knots. The trees should be felled between the 1st of November and the 28th of the following February, when the sap is in the roots. The natural butt of the tree should be left, but the branches and the bark, with all the adhering soft wood, removed, so as to leave a clean, hard, smooth surface. During the process of shipping, etc., the poles must not be left in water for more than seven days.

Larch poles were at one time employed, but it is difficult to obtain the timber free from bends and large knots. Scotch fir is also a possible material, but the supply will not compare with that which is obtainable from Norway. It may therefore be said that pitch pine for square poles and Norway fir for round ones are practically the only materials employed. The supply of Norway poles has of late years become limited, and the area of supply has now been extended to Sweden, Finland, and part of Russia.

When creosoted poles are to be stored they may be piled together as closely as is desired, but the bottom poles should be raised a few inches above the ground by suitable

supports. Timber which has not been subjected to any preservative process should invariably be stacked in such a way as to provide a perfectly free air circulation to every part of the wood.

Preservative Processes.

Wood is subject to deterioration by decay, which may be caused by dry or by wet rot. The former is caused by a species of wood fungus which in time reduces the wood to a fine powder. Since this effect only occurs in very enclosed places where there is no circulation of air, telegraph poles are entirely free from it. Wet rot is, however, of a far more serious character, and a pole which had not been subjected to any treatment would not last more than five or six years—possibly even less. The fermentation of the sap will in time reduce the interior of the pole to a pulpy condition, and, finally, instead of a solid pole nothing more than a shell remains. This state of affairs is readily detected by the hollow sound resulting from a blow with a hammer. The rotting of the pole at the ground-line (frequently termed the "wind and water" line) is of far more frequent occurrence, and is mechanically produced by the continual alterations of temperature and moisture. The temperature above the ground-line is higher than that of the soil, and thus moisture is drawn up each fibre of the wood. This moisture then expands, bursts its cell, and finally escapes as vapour. Wood is extremely durable when kept continuously dry or continuously wet, but is not so when the conditions alternate as rapidly as is the case in this country.

With pitch pine poles the timber is thoroughly seasoned, *i. e.* the sap is slowly dried out under conditions unfavourable to fermentation, secured by giving a good air circulation to *every* part of the wood. Charring the butt by slowly roasting it over a fire and then well tarring it to about one foot above the ground-line proves quite sufficient for this class of timber. The effect of the process is to exclude moisture from the wood, and, with the exception of painting, no other treatment is adopted in this case.

Every other type of timber is subjected to one or other of the various preservative processes. Of these, creosoting

is by far the most efficacious, but care must be taken that the wood is perfectly dry before being treated, otherwise more harm than good results. The life of a pole when properly treated is upon the average in excess of thirty years.

The creosoting process as now carried out consists in injecting creosote into the wood by a process of vacuum and pressure. The quantity of creosote to be injected varies, according to the specifications of different administrations, from 8 to 12 lbs. per cubic foot for telegraph poles, the Post Office specification being 10 lbs. to 12 lbs. The poles to be treated are placed in a closed cylindrical vessel, an air-pump is set to work, which produces a vacuum in the cylinder, opens the pores of the timber, and, to some extent, serves to draw out the moisture. Creosote, heated to a temperature of from 100° to 120° F., is then introduced into the cylinder, the air-pump is stopped and the pressure pumps are employed to force the creosote into the wood.

This process is most satisfactory when applied to well-seasoned and perfectly dry timber since moisture would otherwise be driven into the heart of the wood. Seasoning is produced by allowing a perfectly free air circulation to every part of the timber for a lengthy period—not less than four months under favourable conditions is desirable. In order to save this delay and also to remove every trace of moisture prior to the injection of the creosote, S. B. Boulton devised the following method:—Creosote, heated to a temperature slightly in excess of 212° F., is introduced into the cylinder, and the air-pump, communicating with a dome fitted upon the top of the vessel, is set at work. It will readily be seen that, as the timber is thus subjected to a temperature above the boiling-point of water, any watery moisture contained within the pores of the wood is turned into vapour and is drawn off by the action of the air-pump. The creosote itself is not vaporized since its boiling-point is very much above that of water. When the last trace of moisture has been extracted, the pressure-pumps are employed to inject the creosote. Briefly then, the Boulton process consists in vaporizing the water in the timber by the heat of the creosote, and then withdrawing the vapour by the action of the air-pump before the

injection of the creosote. The Engineering Department of the Post Office, in its treatment of telegraph poles, has availed itself of this simple and efficacious process for some years past, whenever it has been found necessary. It is rather remarkable that this example has not oftener been followed by civil engineers.

Burnettizing consists in the injection of a concentrated solution of chloride of zinc.

Boucherizing consists in the injection of a concentrated solution of sulphate of copper.

Boucherizing is somewhat unreliable, and there is always a definite percentage of failures in which the life of the poles is but five or six years, but those which take the process well may be relied upon for a much longer period. The iron work fitted upon the pole is, however, more or less rapidly destroyed by the action of the copper sulphate. Burnettizing is, perhaps, more reliable, but the average life of poles so treated is not, upon the average, much in excess of twelve years. These two processes have the advantage that the poles can be painted, whereas a creosoted pole cannot, owing to the action of the creosote upon the paint in producing a curious ruddy-coloured covering which, unfortunately, never properly dries. The creosoting process is the one which is normally used; but where, in deference to local opinion, poles are to be painted those treated by the Burnettizing process are employed. It is true that a new paint has recently been devised which is capable of application to creosoted poles, but it is yet too early to express any definite opinion as to its efficacy.

The various processes may be described as consisting in the injection of antiseptics or substances which oppose putrefaction. These substances combine with the sap to form insoluble compounds which cannot be acted upon by air or water. One great advantage of the creosoting process lies in the fact that, owing to its oily nature, it renders the pole perfectly waterproof.

The top of a wooden pole is protected from the elements by means of a galvanized iron pole roof of suitable size (8, 10, or 12 inches wide) fitted transversely to the line of the wires. The pole is cut to receive the sloping sides of the roof, which is secured by clout nails unless the pole

carries a saddle wire, in which case the roof has suitable holes through which the four coach screws supporting the saddle are passed.

In some few cases where ornamental poles are specified pole finials are used instead of roofs and are fitted with a dowel. In the case of square poles the top of the pole is lined with a suitable moulding so that the same form of finial may be employed as for round poles. These finials vary in height from 33″ to 40″, and have precisely the same appearance as those used with iron poles, but differ from those employed by the National Telephone Company, owing to only one ball (instead of two) being formed below the point.

Arms.

The best material for arms is British oak, and this was exclusively used by the Post Office for many years. Owing, however, to its comparative scarcity and consequently enhanced price, it has been necessary to find a substitute, and Australian karri wood, which appears to give excellent results, was finally adopted. The arms are pickled in a solution consisting of green oil (a tar product) and copper sulphate.

The tubular iron arm, which was tried as a substitute for wood, failed on account of the excellent earth connection which it afforded. Workmen sitting upon the arm in more or less damp clothes, upon touching circuits worked with a high E.M.F., such as multiplexes, etc., received very heavy shocks. This is not the case with wooden arms, and the difficulty was surmounted by the use of two insulating strips of wood covering the upper sides of the arm between the insulator bolt-holes upon either side of the pole. The addition considerably increased the cost of the arms, and they are now used only upon iron poles and standards.

In the past 24-inch and 33-inch arms, each carrying two wires, were fixed alternately upon the pole, with the object of minimizing the risk of contact when a wire chanced to fall. The sections of these arms were 3 inches by $2\frac{1}{2}$ inches for ordinary cases, and 3 inches by 3 inches for terminal purposes. Owing to the very considerable increases in the number of wires four wire arms are now universally employed, save upon very small local lines which are unlikely to increase in size.

The standard arm is 48″ × 2½″ × 2½″ for wires weighing 400 lbs. or less per mile, and 48″ × 3″ × 2½″ for larger wires, whilst 48″ × 3″ × 3″ arms are used when the wires are terminated. The arms are bored as shown in Fig. 378 and are earth-wired with 60 lb. G.I. wire.

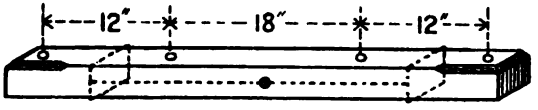


FIG. 378.—A 48-inch arm.

The arms are always fitted upon the London or "up" side of the pole. With the aid of an arm gauge the notches, having a maximum depth of 1½ inches, are cut so as to barely admit the arm, which is driven into the pole by means of a wooden mallet. In order to avoid rotting, the notches are painted over before the insertion of the arm with a mixture composed of one part gas tar and two parts of creosote by measure. In fact, wherever a pole is cut and the inner wood exposed a coat of creosote and tar should invariably be applied.

The centres of the arms are fitted 12 inches apart, and the first arm is placed 9 inches from the top of the pole (Fig. 379). The line wires attached to the four insulators carried by each pair of arms thus form a 12 inch square upon each side of the pole. Upon some of the older lines a 14 inch square was adopted, but this has been abandoned in favour of the standard arrangement described. It may perhaps be stated that the formation of a square is an essential feature of the symmetrical twist system of construction for telephone circuits.

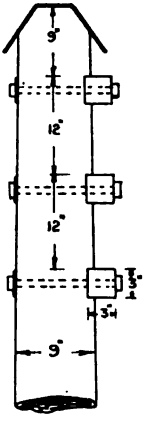


FIG. 379.—Spacing of pole fittings.

The arm bolts are of galvanized iron, each provided with a nut and two washers, and made in various lengths from 6½ inches upwards, with a diameter of ½ inch for the smaller, and ⅝ inch for the larger sizes.

Insulators.

The qualifications of the material used for insulators may be stated as below :—

1. High specific resistance.
2. Homogeneous.
3. Not porous.
4. Should take a high polish.
5. Not subject to deterioration.
6. Readily mounted.
7. Preserves its form.
8. As slight an affinity for moisture as possible.
9. Tensile and compressive strength.
10. Toughness.

The only material which satisfies these conditions is porcelain, and then only when well burnt, so that, a partial vitrification having taken place throughout, it becomes homogeneous and non-porous. The other possible substances which could be used are given below, together with the reasons which make them undesirable.

Material.	Objection.
Ebonite	(5) Subject to surface deterioration.
Glass	(8) Hygroscopic, (10) brittle.
Brown earthenware	(4) Surface not so smooth as porcelain.

Glass is used to a very considerable extent in America, but this is largely because insect growth takes place beneath the sheds of any opaque insulator and so tends to bridge across the bolt and the outer shed. Again the climates of this country and America are of widely different character, and in comparing types of insulator this factor should always be taken largely into account.

The choice of the material for use in insulators is practically limited to porcelain and earthenware. The former is exclusively used where high insulation is necessary, but upon minor lines there is no objection to the use of brown earthenware. It has, moreover, the merit of greater

cheapness, and forms a less conspicuous target for stone-throwing.

The factors which determine the *design* of an insulator are mechanical strength and insulating properties. The latter are secured (1) by increasing the distance to be traversed by a current leaking from the wire to the insulated bolt, (2) by reducing the section of the conducting film, (3) by the retention of a dry surface on one portion of the insulator, and (4) by securing that the general form of the insulator shall not help or retain deposits of dust, soot, etc., nor foster the growth of spiders or other spinning insects.

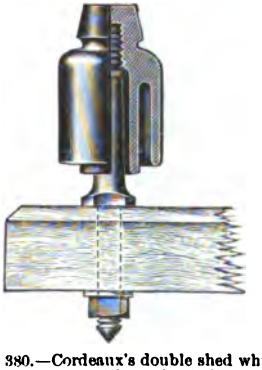


FIG. 380.—Cordeaux's double shed white insulator with steel spindle.

FIG. 381.—Post office terminal insulator.

The insulator spindles or bolts formerly employed were of iron, but these have given place to steel, whilst for heavy stresses and terminations a specially heavy form of the latter is employed.

Most of the earliest forms of insulator were of the fixed bolt type in which the cup was cemented on to the bolt. This type gives a very much lower insulation resistance than the screw-cup type, owing largely, no doubt, to the fact that in the course of time the cement develops small cracks and fissures. Moreover, the removal of the bolt from the arm whenever a damaged insulator had to be replaced was undesirable since the arms were frequently split in the process owing to the bolt having rusted into the arm and become securely wedged.

The standard form of insulator is that designed by J. H. Cordeaux many years ago, and illustrated in Fig. 380. It is mounted upon a steel spindle the upper extremity of which ends in a flange and a coarse screw, whilst the lower part serves for securing the bolt to the arm. The cup itself is of porcelain made in one piece and having a coarse female screw for securing it to the spindle. The cup is screwed down on to the india-rubber washer which is placed upon the upper flange of the spindle. This gives the arrangement a small amount of flexibility which no doubt saves the cup from breakage in the event of sudden stresses, and it also serves to prevent fracture

FIG. 382.—Section of a Langdon insulator.

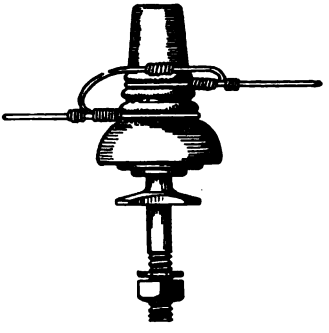


FIG. 383.—View of a Langdon insulator showing the line wire terminated.

of the cup due to the differing coefficients of expansion of the metal spindle and the porcelain cup. The double shed secures a dry and comparatively clean part of the insulator, therefore increasing the resistance which a current encounters in passing over the surfaces from line wire to bolt. The outer shed in course of time becomes black by being coated with the solid matter (chiefly carbon) which the atmosphere contains. Also, the corrosion of the wire, if of iron, adds its quota to this deposit. The time taken for the deposit to accumulate depends entirely upon the character of the neighbourhood, but arrangements are made to periodically remove and cleanse the insulators.

Where wires are terminated as at the junction of under-

ground and open lines, or, where a very sharp turn in the line occurs, terminal insulators are employed. These insulators are of the double shed screw-cup form, but are much heavier and stronger, and are provided with two grooves. The steel bolt is also heavier, with a broad flange, and projects further into the upper portion of the cup, which is so shaped as to keep the point at which the wires are attached near to the arm thus reducing torsional stress upon it. These details will however be sufficiently apparent from a consideration of Fig. 381.

The ordinary standard spindle may be adapted to meet heavy stresses by the addition of a G.I. washer $2'' \times 2'' \times \frac{1}{8}''$ placed between the flange of the spindle and the arm, thus increasing the bearing surface.

The Langdon insulator is in very considerable use, and

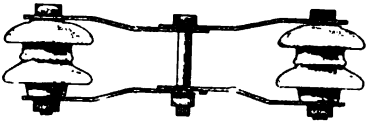


FIG. 384.—Double shackle insulator.

Figs. 382 and 383 showing its construction are given for purposes of comparison with the types already mentioned.

The shackle type of insulator is now rapidly disappearing, but there are still many in use upon minor lines. Its arrangement will be apparent from Fig. 384. It may be pointed out that the current in escaping from the line to the bolt has two paths, one over the upper and one over the lower surface, hence the insulation is extremely low. The line wire is also jointed at each shackle.

The side knob form of insulator (Figs. 385 and 386) is frequently employed to reduce the amount of covered wire required to lead a circuit into an office.

Where it is necessary to terminate heavy conductors the vertical spindle of the insulator tends to cant the arm. In order to avoid this difficulty "J" bolts fitted with screw-cups of the terminal form are frequently employed (Fig. 387). The advantage gained is that the stress is applied directly in the plane of the arm-bolt, and there is therefore no tendency towards canting. Moreover, the arms are in such cases invariably fixed upon the further side of the

pole so that the stress is not taken by the arm-bolt. The

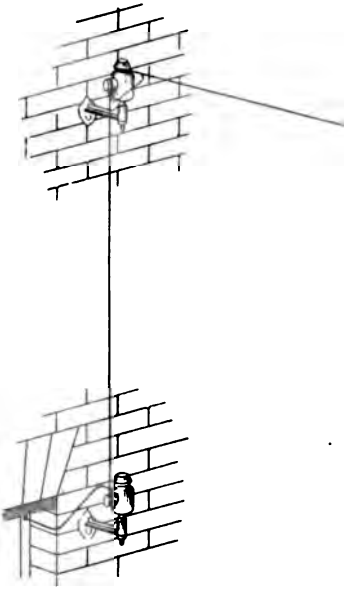


FIG. 385.—Leading by means of side-knob insulators.

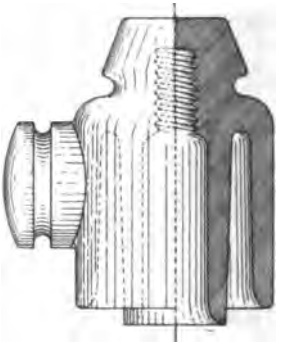


FIG. 386.—Side-knob insulator.

bolt is of $\frac{3}{4}$ inch galvanized iron when used for heavy conductors, but a lighter form ($\frac{5}{8}$ inch) is frequently employed upon roof structures or where the conductors are of small gauge terminated upon $2\frac{1}{2}'' \times 2\frac{1}{2}''$ arms.

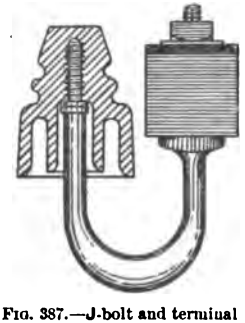


FIG. 387.—J-bolt and terminal insulator.

The terminal spindle is therefore only employed in those cases in which it is necessary to terminate wires upon both sides of the pole, as, for example, in the case of a route of open wires crossing a railway line. In every case in which the use of such a spindle would produce a torsional stress upon the arm J-bolts are invariably substituted.

It may be pointed out that insulators (known as "medium" insulators) of the same general pattern as that illustrated in Fig. 380 are made in a smaller size for use with $\frac{5}{8}$" J-bolts, where there is insufficient space for the "large" or standard size.

Choice of Material for Line Wire.

The choice of the material for use as line wire is practically restricted to iron, copper, and bronze. The latter possesses the advantage that it can be used safely in smaller sizes than either iron or copper. The breaking weight of a 40 lb. bronze wire is 200 lbs. whilst that of a 70 lb. wire is 345 lbs., or rather more than that of a 100 lb. copper wire. The resistance is, however, very much higher, an ohm-mile of bronze wire weighing 1963·5 lbs. (see table, page 674). The 70 lb. wire has hitherto been employed for telephone subscribers' aërial wires in connection with the Post Office London telephone system. It has recently been decided to adopt 40 lb. conductors having a breaking weight of 200 lbs. and a resistance of 49Ω per mile. It may be remarked that as the proportion of silicon or aluminium is increased the ductility and conductivity are reduced whilst the tensile strength is enhanced. Phosphor bronze wire has a conductivity equal to 40 per cent. of that of copper with a tensile strength proportional to 80,000 lbs. per square inch for even the finer wires.

For telegraph circuits four sizes of iron wire are employed, viz. 200 lb., 400 lb., 600 lb., and 800 lb. The light wire is used for all minor circuits, whilst the use of 800 lb. wire is confined to very long high speed circuits. It is however not so satisfactory from an electrical point of view as 150 lb. copper. The 400 lb. wire is the standard for all telegraph circuits which do not come under the headings of minor or very long high speed circuits. Iron wire is subject to deterioration, and when taken down it is almost valueless, whereas old copper wire is nearly as valuable as new. There is however a distinct difference in favour of iron between the cost of a 100 lb. copper and a 400 lb. iron wire, and it is to this fact that the continued use of the latter is due.

The resistivity of iron is over six times as great as that of copper, and therefore there is a decided gain from an electrical point of view in the use of 100 lb. copper wire in preference to 400 lb. iron. The 600 lb. and 800 lb. iron wires are not in extensive use, and it is scarcely likely that either will be again employed upon new circuits.

The use of the lighter copper wires in place of iron results in an increase in the number of circuits which can safely be added to a pole line. Again, during storms, the lighter copper wires break instead of the poles since the stress to which the pole is subjected is but a fourth of that resulting when a tree falls upon an iron wire line. It is far easier to deal with a breakdown in which the supports are intact than one where several poles are broken. However, the demand for copper is so great that its price is very high, thereby precluding its use in all but essential cases, such as telephone circuits.

The weight of snow and ice which a wire will carry before breakage varies with the gauge of the wire—for instance, a 150 lb. copper wire would carry only one-fourth the weight of ice which a 600 lb. wire would safely bear if erected in a span of equal length. Since the quantity of ice which adheres to the wires is found, under like circumstances, to be practically the same with every gauge of wire, the light wires may be loaded up to, or beyond, the breaking point whilst the heavier wires are but little affected. It is from this point of view that the diameter of open wires may not be reduced below a certain point. For main lines 150 lb. wire is usually the lightest type of conductor employed, whereas in towns and other more or less sheltered positions 40 lb. bronze wire may quite safely be utilized. Again, the same gauge of wire erected in 60 yard spans would safely carry twice the weight of ice per yard run as it would in 85 yard spans.

Iron Wire.

The manufacture of the iron wire is a comparatively simple process. The pigs of iron are puddled in a furnace, hammered into compact form, passed through a series of rollers which continually reduce the diameter of the wire, and finally through a number of dies of regularly diminish-

ing size. The wire is drawn through these dies whilst cold, but the dies do not come into the process until the limit of the rolling mills has been reached. The wire is then thoroughly "galvanized" by passing the wire, after heating and chemical cleansing, through a bath of molten zinc. This process protects the wire from rapid oxidation and so lengthens its life. The outer layer of zinc becomes oxidized upon exposure to the elements, but as zinc oxide is insoluble this layer forms a protective coating which secures the iron from oxidation.

Before wire is accepted from manufacturers it is subjected to a series of tests which may be divided under three headings, viz. form, mechanical properties, and electrical properties. In the case of iron wire a test is also applied with the object of ascertaining if the galvanizing has been satisfactorily performed.

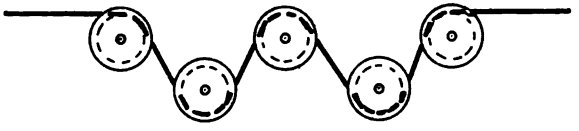


FIG. 388.—Arrangement of rollers for the testing of iron wires during manufacture.

It is essential that the possibility of breakage due to defects in manufacture shall be carefully guarded against, and with this object the maximum tensile strength combined with ductility or absence of brittleness is specified.

Since maximum resistance per mile together with weight and gauge are set forth the specific resistance of the wire is specified by implication.

The various details of the tests will be apparent from the summary given below. It may be remarked that the tests are made upon samples chosen at random.

Form.—(1) The wire must be perfectly cylindrical and of uniform diameter. (2) It must be free from scale, inequalities, flaws, splits and other defects.

(1) This is measured by a micrometer at one or more points in every piece.

(2) (*a*) The wire is closely examined by the eye. (*b*) The absence of splits is determined by passing the wire over four or more rollers placed in positions selected by the

Inspecting Officer (*e.g.* as in Fig. 388), and is sufficiently stretched to remove all bends or sinuosities.

Ductility.—The wire is gripped between two vices, one of which revolves at a speed not exceeding one revolution per second, thus subjecting the wire to torsional stress. A straight ink mark is made upon the wire which, during the torsion, becomes a spiral mark upon the wire. The twisting is continued until the wire breaks when the number of spirals counted must not be less than the number specified in the table.

Galvanizing.—A sample cut from any coil of wire at random is plunged into a solution of sulphate of copper saturated at a temperature of 60° Fahrenheit, and allowed to remain immersed for one minute. It is then removed and wiped clean. This process is performed four times with each sample of line wire, but only twice in the case of binding wire, without there being any sign of a reddish deposit of metallic copper upon the wire, which would be the case were the galvanizing too thin.

The wire should be capable of being bent round bars of the following diameters without the galvanizing showing any signs of cracking or peeling off:—

For 800 lb. wire	$2\frac{1}{2}$ inch bar,
„ 600 lb. „	$2\frac{1}{4}$ „ „
„ 400 lb. and 450 lb. wire	$1\frac{3}{4}$ „ „
„ 200 lb. wire	$1\frac{1}{4}$ „ „

Tensile Strength.—The wire must be capable of lifting a weight equal to nine-tenths of the minimum breaking weight for the size of wire under test. The remaining tenth is added gradually in weight equal to at least one-hundredth of the total breaking weight.

Electrical Properties.—The resistance of each test piece (minimum length $\frac{1}{30}$ of one mile) is reduced to the standard inversely as the square of its diameter and is calculated for a temperature of 60° Fahrenheit. In the event of dispute as to the diameter of the wire the test piece is weighed and the weight of one mile calculated. If the resistance per mile multiplied by the weight per mile exceeds 5328 the consignment is rejected.

GALVANIZED IRON WIRE.

Weight per statute mile.		Diameter.			Tests for ductility and strength.						Maximum resistance per mile of the standard size at 60° Fahr.	Limits of weight of each piece or coil of wire.
Standard.	Range allowed.	Standard.	Range allowed.	Approximate standard wire gauge.	Minimum breaking weight.	Required number of twists in 6 inches.	For breaking weight not less than	Required number of twists in 6 inches.	For breaking weight not less than	Minimum number of twists in 6 inches.		
lbs.	lbs.	mils.	mils.	mils.	lbs.		lbs.		lbs.		Standard ohms.	lbs.
800	767 833	242	237 247	3½	2,480	15	2,550	14	2,620	13	6·66	90 120
600	570 630	209	204 215	5	1,800	19	1,850	18	1,900	17	8·88	90 120
450	427·5 472·5	181	177 186	6½	1,350	23	1,385	22	1,420	21	11·84	90 120
400	380 420	171	167 175	7½	1,200	24	1,230	23	1,260	22	13·32	90 120
200	190 210	121	118 124	10½	600	30	620	23	640	26	26·64	40 65
60	57 63	66	64 68	16	Used only for binding and jointing.					25 in 3 ins.	—	5 14

COPPER WIRE.

Form.—The wire must be perfectly cylindrical, uniform in quality, pliable, free from scale, inequalities, flaws, splits, and other defects. This is tested by micrometer and by visual examination.

Ductility.—(1) The wire must be capable of being wrapped in six turns round wire of its own diameter, unwrapped, and again wrapped, in six turns round wire of its own diameter in the same direction as the first wrapping without breaking.

(2) The wire is gripped by two vices, one of which will be made to revolve at a speed not exceeding one revolution per second. The twists thus given to the wire are reckoned

by means of an ink-mark, which forms a spiral on the wire during torsion, the full number of twists to be visible between the vices.

Tensile Strength.—Tests for tensile strength are made with a lever or other machine.

Electrical Properties.—The electrical resistance of each test piece or sample (minimum length $\frac{1}{30}$ mile) shall be reduced according to its diameter, and shall be calculated for a temperature of 60° Fahrenheit.

HARD DRAWN COPPER WIRE.

Weight per statute mile.		Approximate equivalent diameter.		Approximate standard wire gauge.	Minimum breaking strain.	Minimum No. of twists.		Maximum resistance per mile when reduced to standard diameter.	Weight of each piece or coil of wire.
Standard.	Range allowed.	Standard.	Range allowed.						
lbs.	lbs.	mils.	mils.	No.	lbs.			Standard ohms.	lbs.
800	784 816	224	221½ 226	4½	2,400	In 6 inches.	15	1·098	100 140
600	588 612	194	192 195½	6	1,800		20	1·464	
400	392 408	158	156½ 160	8	1,250		25	2·197	
300	294 306	137	135½ 138½	9½	950		30	2·929	
200	196 204	112	111 113	11½	650	In 3 inches.	20	4·329	
150	147 153	97	96 98	13	490		25	5·857	75 100
100	98 102	79	78½ 80	14	330		30	8·785	
182	*178* *186*	(*40*)	(40½ 39½)	7/19	580		60	4·992 (34·36)	50 70
113	*110* *115*	(*48*)	(47½ 48½)	3/18	350		50	8·112 (23·85)	30 60
BRONZE WIRE.									
70	68 72	66	65 67	16	345	15 in 3 ins.		23·05	30 50

Binding-in.

Iron wire is bound to the insulator with 60 lb. iron wire, of which four feet is required for 400 lb. wire and three for 200 lb. wire. The method of binding-in is shown in Fig. 389, and is preferable to the method formerly

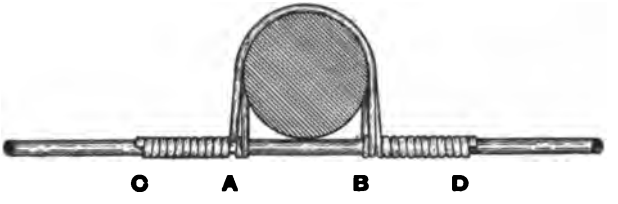


Fig. 389.—Method of binding-in iron wires.

in use. Two laps of binding wire are taken over the line wire at *A*. The inner end is then taken round the neck of the insulator to the under side of the line wire at *B*, and

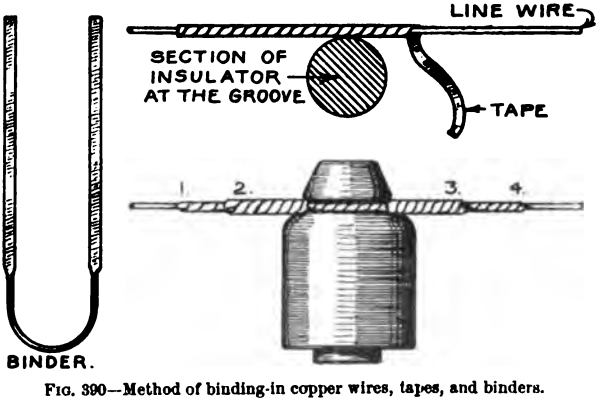


Fig. 390—Method of binding-in copper wires, tapes, and binders.

after one complete lap is taken back round the insulator to *A*, and lapped on the line wire for about a dozen turns to *C*. The other end of the binding wire is taken from the under side of the line wire at *A* round the neck of the insulator to the upper side at *B*, and similarly lapped over the line wire to *D*.

Copper wires are secured to the insulators by binders

and tapes. The binder consists of a round copper wire of suitable size with flattened ends. The tape is 47 mils thick, is tightly lapped round the line wire with the aid of a pair of tongs having roughened jaws, and serves to prevent chafing due to the swinging of the wires under the influence of wind. The arrangement is shown in Fig. 390, and it may be said to be quite the most effective method of binding which has yet been devised. In the event of the line wire breaking in the span the binder holds the wire quite securely, and prevents it from running back. It is, however, quite essential that the binder should be lapped round the wire in opposite directions upon either side of the insulator. The first two turns of the binder round the line wire and tape are formed by the round portion of the binder. The dimensions of the tapes and binders used for the various types of line wire are given below :—

FIG. 391.—A joint in the line wire.

Weight of wire per mile.		Length of binder.	Copper tape (47 mils thick).	
Line.	Binder.		Length.	Width.
lbs.	lbs.	Inches.	Inches.	Inches.
800 } 600 }	400	19	24	$\frac{1}{4}$
400 } 300 }	200	19	23	$\frac{3}{16}$
200 } 150 }	150	17	22	$\frac{5}{32}$
100	100	17	22	$\frac{5}{32}$

JOINTS.

The form of joint used for line wires is of the well-known Britannia type, but the ends of the conductors are nicked and broken off before the three turns of binding wire is applied to each single conductor. For jointing iron wires 60 lb. G.I. is used and for copper wires 50 lb. tinned

copper wire. The wires are lapped as shown (Fig. 391) and soldered, care being taken not to apply any more heat than is necessary so as to avoid annealing the wire. The flux employed is known as Baker's soldering fluid, and to secure a satisfactory joint the wires must be scraped quite clean before jointing is attempted. In the case of copper wires especial care is requisite in soldering, and the joint should be allowed to cool gradually, and should never be chilled by placing it in water.

For large conductors such as 600 lb. and 800 lb. copper or iron wire two pieces of binding wire of the same material are placed in the spaces between the conductors in order to ensure a solid joint. This is illustrated in Fig. 392.

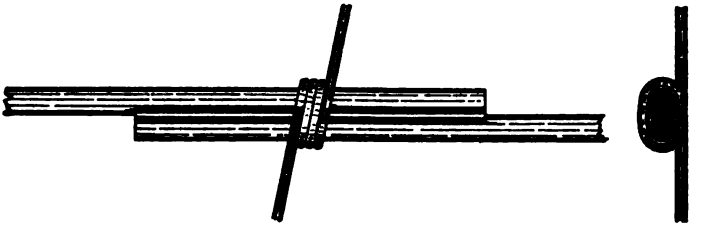


FIG. 392.—Method of jointing large conductors.

Defective joints, due to carelessness or lack of cleanliness, cause considerable trouble in the few cases where they exist. Water enters the joint, and its resistance is not only high but is variable, and upon telephone circuits noises are at once produced. Since the defective joint may occur in the centre of a span it is only possible to trace it by a series of localization tests.

EARTH WIRING.

In order to prevent current leaking from wire to wire *viâ* the insulators and arms and also to provide a lightning conductor every pole is "earth-wired." The arms are earth wired, as shown by the dotted lines in Fig. 378, the arm-bolt making connection with the wire when fixed in position. A 400 lb. G.I. wire is fitted to the side of, and is looped at right angles around, but it is not soldered to, the arm

bolt; it is thus clamped between the bolt-head and the washer which is interposed between the bolt and the back of the pole. The upper end of the wire projects above, but should not make contact with, the pole roof, and acts as the point of the lightning conductor, whilst the remainder of its length is stapled down the pole to the butt, on the bottom of which it is stapled in two or three turns in the form of a volute. In all ordinary soils this provides a sufficiently good earth for the purpose, but in rock, or upon viaducts, it is better to omit the earth wire unless a special wire well earthed at the ends of the sections is provided for linking up the whole of the earth wires.

With the poles and arms earth-wired the current which escapes over the insulator to the arms is provided with a path direct to earth and therefore does not leak on to other circuits. Without this provision wires which occupied the same relative positions upon the arms for very considerable distances exhibit partial contact during wet weather. It is true that earth-wiring reduces the insulation of the circuits, but it is preferable to do this rather than to have even one-tenth part of the current so lost making its appearance upon other circuits.

In neighbourhoods where iron wire will not last, old copper wire, secured by copper staples, is frequently used for earth-wiring, but owing to the extra cost this course is is only adopted where it is imperatively necessary. It is moreover desirable to groove the poles to receive the wire for at least 6 feet above the ground-line, thus rendering it difficult for the wire to be stolen.

Dimensions of Poles.

The length of the poles required to erect a given line is determined by the obstructions encountered *en route* but with the qualification that the lowest wire upon the line, when carrying the maximum number of wires for which it is designed, shall not be less than 12 feet from the ground upon country roads, nor less than 20 feet at road-crossings, or over railway lines. In villages or small towns the lowest wire should be given a greater elevation in order to secure immunity from wilful damage, and also to keep the wires above the top windows of the houses which

they pass. It is firstly necessary to determine the number of wires which the line will ultimately carry in order to decide the height of the timber.

The diameter of the pole is determined by its length and the maximum wind pressure to which the structure, with its ultimate number of wires, is likely to be subjected. The wind pressure is made up of two parts, that acting directly upon the pole itself and that exerted upon the wires which it carries. These points will, however, be separately dealt with later.

In order to meet the varying requirements three classes of poles are used and are respectively known as light, medium, and stout poles. The type to be used is fixed by the *ultimate* number of wires which the line will be required to carry:—

Light poles from 1 to 5 wires
Medium „ „ 6 to 10 „
Stout „ over 10 wires

The poles are stocked in lengths varying from 18 feet to 85 feet.

The dimensions of a 30 foot, 40 foot, 50 foot, and a 60 foot pole of each of the three classes are given below for purposes of comparison.

Length of poles.	Sizes of light poles.			Sizes of medium poles.			Sizes of stout poles.		
	Diameter at top.		Minimum diameter at 5 feet from butt end.	Diameter at top.		Minimum diameter at 5 feet from butt end.	Diameter at top.		Minimum diameter at 5 feet from butt end.
	Minimum.	Maximum.		Minimum.	Maximum.		Minimum.	Maximum.	
30	5	6	7¼	6	7¼	8¾	7½	9½	10¾
40	5	6½	8	6	7½	9¾	7½	9¾	12
50	5¼	7	9½	6½	8¼	11½	7¾	10¼	13¾
60	5½	7¾	11	7	8¾	13¼	8	10½	15½

The distances between the poles vary from 60 to 75 yards, according to the type of line. For minor lines of light character 80 yards (22 poles per mile) is the standard

span, but upon important routes 60 yard spans (30 poles per mile) are adopted. These figures, however, represent the ideal conditions, but in practice many modifications are necessary. In constructing a route the wayleave question enters into the problem to a serious extent, and therefore an 80 yard span upon a heavy main line is by no means the rarity one would desire. Where staying facilities cannot be obtained it is often necessary to reduce the lengths of the spans so as to distribute the lateral stresses over a larger number of poles.

In the London telephone system 70 yards has been adopted as the standard span; but it must be recollected that the lines are invariably of 70 lb. bronze wire, whereas main telegraph and telephone trunk lines carry much heavier conductors.

Depth to which Poles are Buried.

In ground of ordinary character poles are buried to a depth equal to one-fifth of their length, subject to the qualification that no pole shall be buried less than four, nor more than six feet. In loose ground some extra depth is given, whilst in rocky ground it is not necessary to go quite so deep. Again, it may in special cases be necessary to set the poles in Portland cement concrete formed by mixing one part of Portland cement, one part of river sand or screened gravel, and four parts of screened river ballast or broken brick or stone of such a size as to pass through a $1\frac{1}{2}$ inch ring. These are matters which require experience to satisfactorily deal with, and no rule which fits every case likely to arise can be given. The pole should be buried to the minimum depth which will ensure that it will not be pulled over by the wires, and that in the event of an extraordinary stress the pole will be held by the ground until the breaking-point is reached.

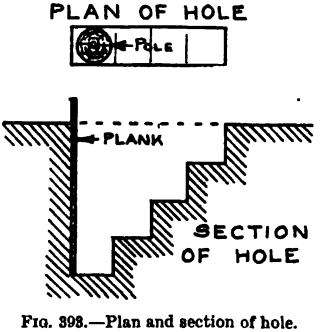


Fig. 398.—Plan and section of hole.

The post-holes, which should be made as narrow as

possible and stepped as shown in Fig. 393, are dug in the line of the wires wherever possible in order that the pole may be bedded against solid earth, for no matter how thoroughly the earth which has been removed is punned when replaced it is never as solid as that which has remained undisturbed. Under normal circumstances there is little or no tendency for the pole to move in the direction of the length of the wires, whilst there is only the rigidity of the earth in which the pole is buried to prevent its rocking laterally due to wind-pressure.

In marshy ground it is advisable to fix a block of wood at the butt in the same manner as with strutted poles. In some cases the pole is blocked at the base and also just below the ground line, large stones frequently being added in order to increase the bearing surface. These blocks may be formed from sound lengths of old poles, split down the centre, coated with creosote and tar mixture and secured to the pole by G.I. spikes. The flat sides of the two blocks should bed against the solid earth in the line of the wires and should be fitted upon opposite sides of the pole, the upper block being placed upon the side towards which the pole is likely to be displaced as the result of lateral stress due to the wires forming an angle at the pole or produced by the prevailing winds. The lower block prevents the pole from sinking, and at the same time keeps the base of the pole immovable owing to the comparatively large area which it offers to movement through the soil. In similar manner the upper block prevents movement at that point, so providing the rigid structure which it is the prime object of all good construction to secure.

Newly creosoted poles frequently exude a quantity of creosote after their erection, and in order to prevent it from flowing on to the pavement a depressed space is left around the base of the pole to allow the creosote to sink into the earth. In some cases it is also desirable to fit wooden laths around the lower part of the pole in order to obviate any risk of damage to the clothes of persons using the road, but the lagging is, of course, removed immediately the creosote has dried.

Stays.

At angles in the line the poles are subjected to a lateral

stress tending to pull the pole over in the direction which would eliminate the angle. The design of poles capable of withstanding this stress, in addition to that resulting during a gale, is quite impracticable on account of the size and cost of the structure necessary. Wherever possible stranded iron wire stays are employed, on account of their small cost and efficiency. The stay wire employed is of two types, viz. either four or seven strands of No. 8 galvanized iron wire. The breaking weight of the former is from 50 to 55 cwt., and of the latter 87 to 91 cwt. The type of wire chosen depends, of course, upon the stress which it is required to withstand; but this point is dealt with subsequently.

The efficiency of a stay is in proportion to the length of the spread, and the stay has to bear the least stress when

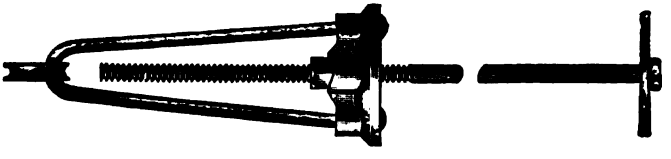


Fig. 394.—Stay rod and bow with ratchet nut.

it makes an angle of 90° to the pole. To obtain a very wide angle would entail the use of a considerable length of stay wire, and it would therefore be more economical to provide two stays making a smaller angle with the pole; for ordinary lateral stays the spread should not exceed half the height of the resultant.

The function of the stay rod and bow is to connect the stay wire to the buried stay block, and to provide a means of adjusting the tension upon the stay wire. The upper end of the rod (Fig. 394) is provided with a screw thread and nut, which latter normally holds the stay bow in position. The stay wire is passed round the thimble upon the stay bow and spliced, and the nut is then tightened by means of a spanner. In order to prevent the nut from untwisting and so allowing the stay to become slack the base of the bow and the nut are cut so as to form a ratchet.

The rods are made in three sizes, viz :—

				Breaking weight.
6 feet long and	$\frac{5}{8}$	inch in diameter :—		95 cwts.
8 „ „	$\frac{3}{4}$	„	„	140 „
8 „ „	1	„	„	260 „

The first-named size is only employed where $\frac{4}{8}$ stay wire is adequate, whilst the last-named is usually employed in connection with "V" stays or other cases of excessive stress.

The stay rod is passed through a hole in the centre of the stay block, which consists of a creosoted block of redwood of one of the three sizes detailed below :—

Description.	Dimensions in inches.		
	Length.	Breadth.	Thickness.
Light	24	10	5
Medium	36	9	4½
Heavy	42	10	5

The large square washer which is placed between the bolt-headed end of the rod and the stay block serves to secure a satisfactory bearing surface against the wood. Without this washer the rod would, in course of time, work its way through the block.

The stay blocks are buried to a depth of from 3′ 6″ to 6′ according to the nature of the ground and the stress to which the support will be subjected. It may, however, be remarked that only stays upon very light lines should be buried to the minimum depth.

The hole for the stay (Fig. 395) should be undercut, and the earth removed to allow the rod to come into line with the stay should be as narrow as possible. In this way a bedding of solid earth for the block to pull against is secured, and, under ordinary circumstances, there is little chance of the stay being drawn or uprooted.

In rock a hole is sometimes drilled and the rod leaded into it. This method is far less costly than forming a hole in the ordinary way, and is, moreover, quite as efficient if the work is carefully performed.

Where one stay is sufficient to take the stress exerted

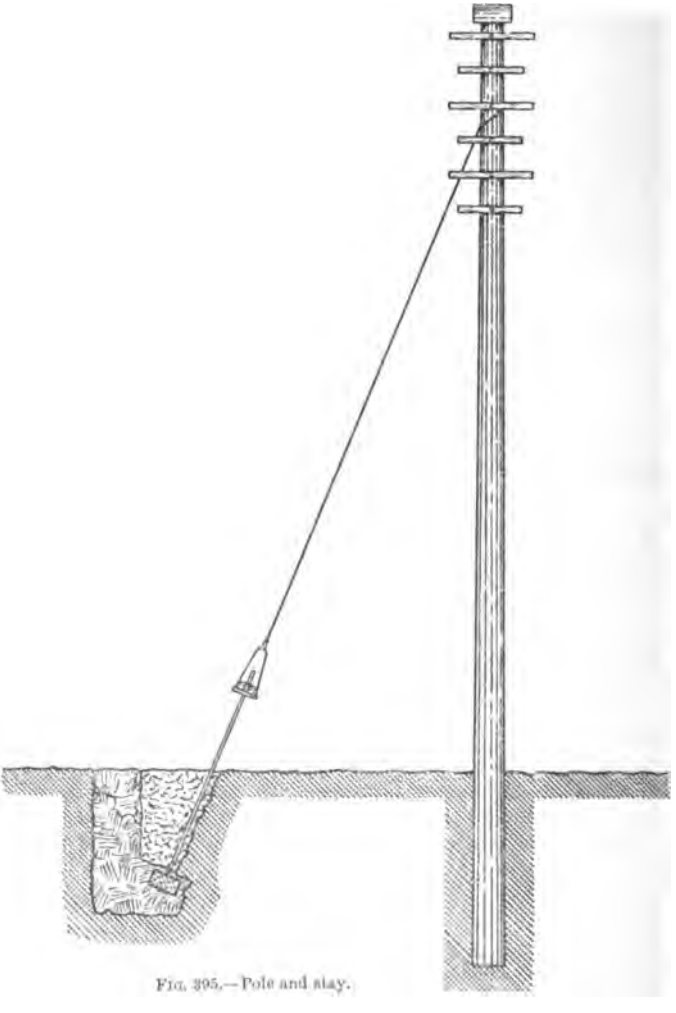


Fig. 395.—Pole and stay.

upon a pole this stay should be fixed at the centre of the stresses produced by the wires, or at the "resultant point,"

as it is usually termed. There will then be little or no tendency for the pole to buckle. The effects of disregard of this rule are rendered sufficiently obvious by Figs. 396 and 397.

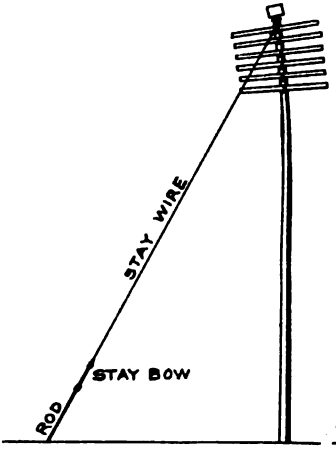


FIG. 396.—Stay attached above the resultant point.

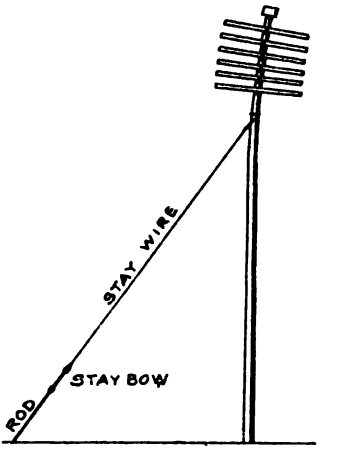


FIG. 397.—Stay attached below the resultant point.

The stay should act directly against the force exerted by the wires, and should bisect the greater angle made by the wires (Fig. 398).

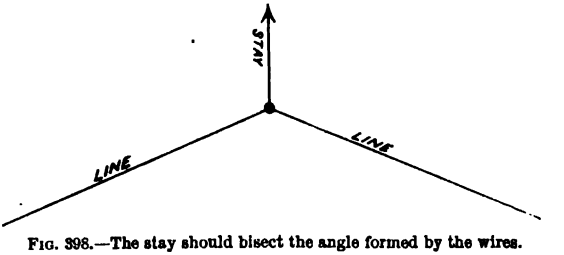


FIG. 398.—The stay should bisect the angle formed by the wires.

The screw thread of every stay rod should be kept coated with a mixture composed of 45 parts of tallow, 45 parts of coal-tar, and 10 parts of mineral pitch, in order to prevent its destruction by rust.

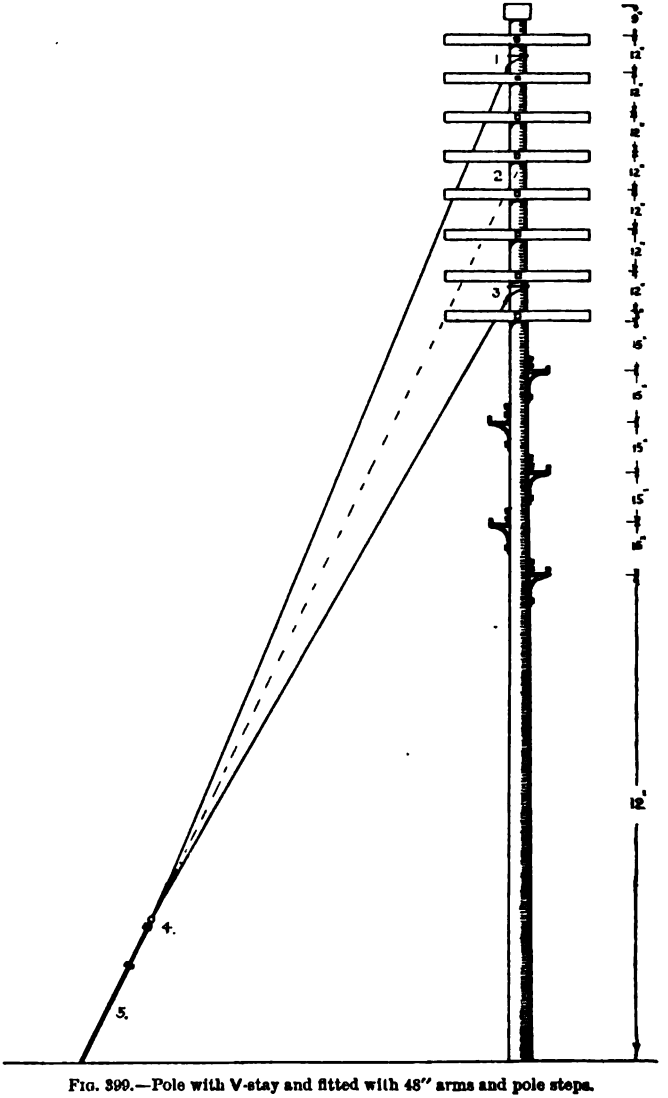


FIG. 399.—Pole with V-stay and fitted with 48" arms and pole steps.

Frequently it is necessary to fix stays upon the grassy margin of a road, in the line of the kerb, or in other comparatively open positions, and, in order to avoid any risk of users of the road colliding with them, it is essential that the stays shall be made as conspicuous as possible. A stay guard, used in these special cases, consists of a length of half round timber, painted white, with the round side outwards, and lashed to the stay rod with G.I. wire, the flat side of the guard being recessed to receive the bow whilst the upper end finishes in a point. Such guards are frequently, if not invariably, made by sawing old poles into suitable lengths (the guard should extend at least six feet above the ground) and then cutting the blocks down the centre.

Where two stays are required on account of the heavy stress, they should be fixed at equal distances above and below the resultant joint, as indicated in Fig. 399. In this case a "V-stay" is shown, whilst in Fig. 400 two parallel stays are depicted. The former arrangement is in

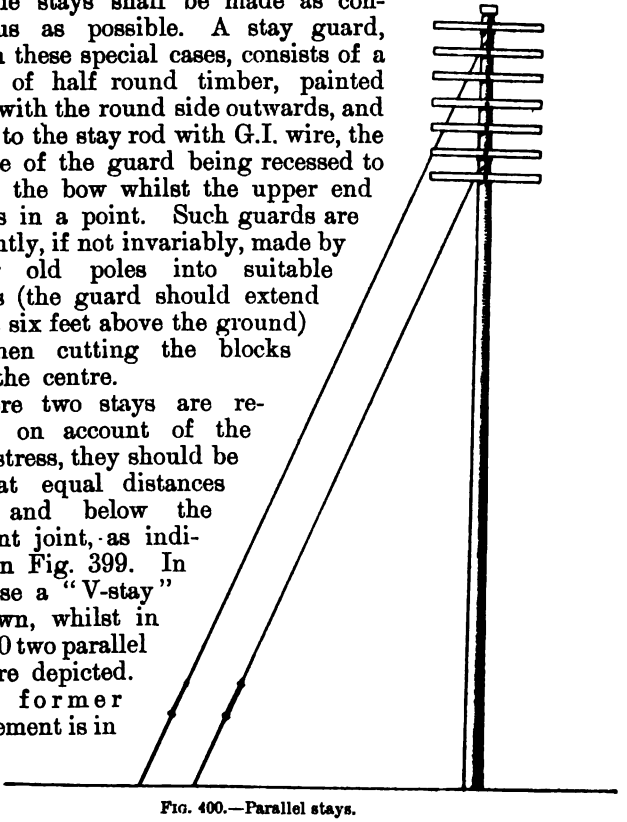


FIG. 400.—Parallel stays.

many cases to be preferred, and especially so where the line carries its full capacity of wires. The stay wire is in one continuous length, which passes round the thimble of the stay bow, where both sides are bound together with No. 11 G.I. wire. When such a stay is fixed upon grazing land the two sides of the wire should be secured together at least

8 feet above the ground, so as to make it impossible for the animals to wedge their heads in the angle formed between the two sides of the stay.

The advantage of parallel stays lies in the fact that the second stay may be added without touching the first. Thus, in erecting a new line to carry 6 wires immediately, and, say 32 wires ultimately, the first stay would be fixed

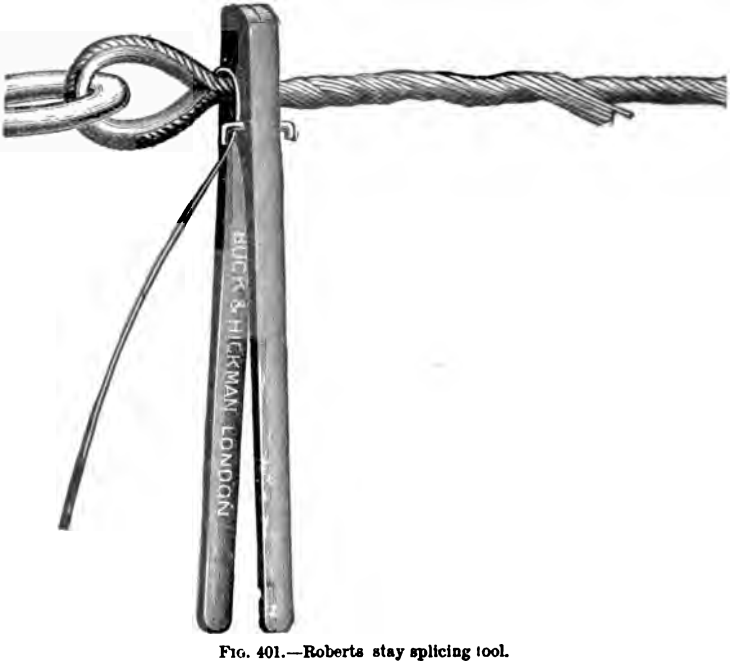


FIG. 401.—Roberts stay splicing tool.

in the position which it should occupy when the line is full. When the need for the second stay arises due to the addition of wires it may be fitted without in any way interfering with the first.

With parallel stays care must be taken that the stays are accurately parallel, since nothing more unsightly than stays at differing angles to the pole can readily be imagined. This remark does not apply to a V-stay, since the line of the

rod bisects the angle made by the two sides of the stay. If a V-stay is inadequate then parallel stays are used, but never a combination of a V-stay and a single stay.

The number of stays required to counterbalance the stresses exerted by a large number of wires at the first pole upon the line is occasionally so many that the resulting structure would be of a most unsightly character. In such cases $1\frac{1}{2}$ inch round solid iron rods are frequently employed instead of the stranded stay wire, a malleable iron casting for clipping the pole being attached to the rod. A special spiked fitting is clipped on to the rod so as to prevent boys climbing up the stays, but the points are not sufficiently sharp to cause injury to cattle. With stranded stay wires barbed wire is often fitted at a height of not less than 10 feet above the ground-line.

The method of fixing the stay to the pole is to take the end of the stay wire twice round the pole, and to "make it off" upon itself. The first turn round the pole should be parallel with the ground line, whilst the second turn should come downwards in the direction of the stay. Where the two sides of the wire cross at the back of the pole a single staple is put over both.

The same form of splice, devised by M. F. Roberts, is made at the stay bow and at the pole. The loose end of the stay is unstranded, and the wires placed symmetrically around the part of the stay wire to which it is to be spliced. Each wire is successively bound round the stay wire, and the remaining strands thus :—

1st	wire	8	laps	around	main,	binding in	6	loose wires
2nd	,,	8	,,	,,	,,	,,	5	,,
3rd	,,	7	,,	,,	,,	,,	4	,,
4th	,,	7	,,	,,	,,	,,	3	,,
5th	,,	7	,,	,,	,,	,,	2	,,
6th	,,	6	,,	,,	,,	,,	1	,,
7th	,,	6	,,	,,	,,	,,	—	,,

The length of the completed splice is about $8\frac{1}{2}$ inches. For $\frac{4}{8}$ strand the four wires should make 8, 8, 7, and 7 laps respectively.

The work is considerably facilitated by the use of the Roberts' stay tool depicted in Fig. 401.

Under no circumstances should a stay wire approach within 3 inches of any line wire, and where the circumstances are such that this clearance cannot otherwise be obtained a $\frac{3}{4}$ inch G.I. stay crutch of the form shown in Fig. 402 is fitted. The three legs are secured to the pole by means of coach screws and the stay bound in so as to prevent it from being jerked out of the fork by motion of the pole due to sudden gusts of wind. The crushing or breaking stress of a stay crutch itself is 5 tons.

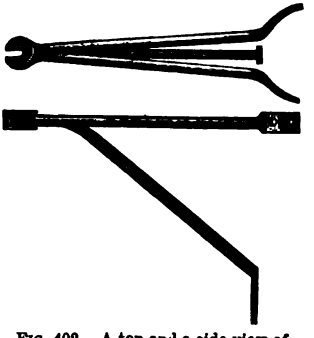


FIG. 402.—A top and a side view of a stay crutch.

A pole spur (Fig. 403) is frequently used in those cases in which the stay has to be fixed within say 12 or 15 inches of the pole, It is somewhat shorter than a stay crutch but is provided with an upper leg, and the $\frac{3}{4}$ inch size has a breaking stress of 7 tons. The fitting is occasionally employed to truss a pole, as for instance in the case of an angle pole which cannot be stayed.

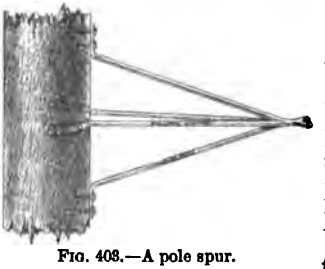


FIG. 403.—A pole spur.

The pole may be blocked at the butt and just below the ground-line (as previously described) thus securing that the base of the pole shall be perfectly rigid. In order to strengthen and to prevent the pole from buckling, a pole spur is fitted half-way between the resultant and the end of the pole, and a length of stay wire is then secured to the pole at the resultant point, passed over the spur, and is terminated upon an ordinary stay rod which is fixed by nailing its G.I. washer beneath the butt of the pole. The arrangement is not altogether satisfactory and is only adopted in very special circumstances.

STRUTS.

A stay may be defined as a support which is subjected

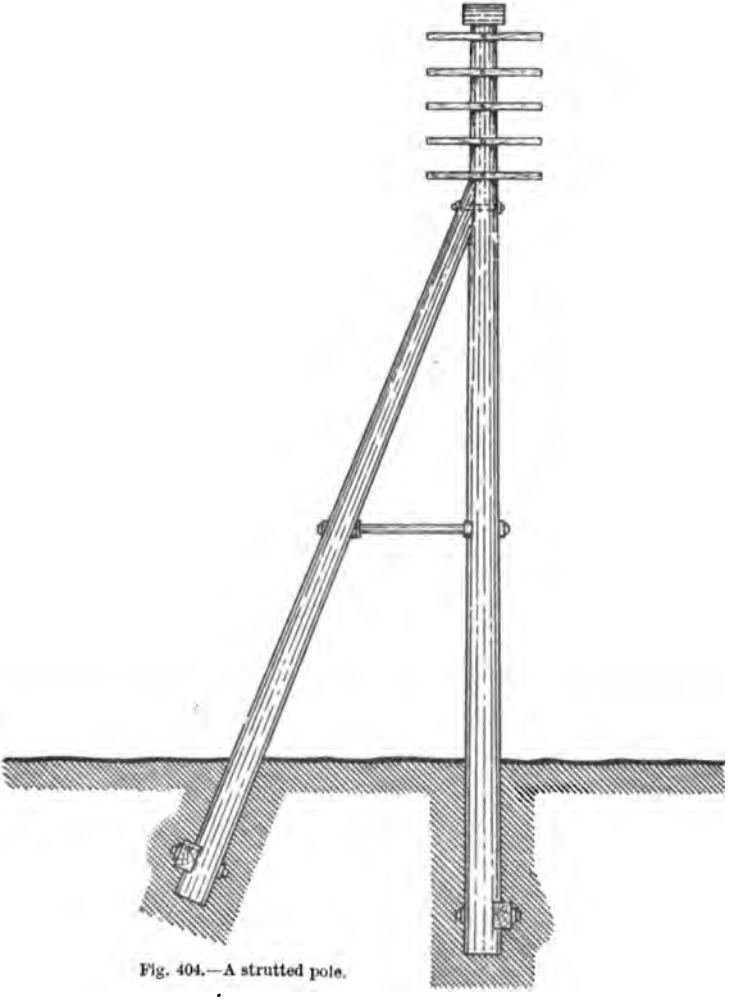


Fig. 404.—A strutted pole.

to tensile stress, whereas a "strut" is primarily designed

to withstand a compressive or crushing stress. When erected in the manner to be described a strut will also act as a stay, but its cost is considerably higher and its use is, in practice, restricted to those cases in which it is impossible to use a stay. With the old 24 and 33 inch arms a strut could usually be fitted at, or very near to, the resultant point, but with 4-wire arms, such as are now universally employed consequent upon the growth of the lines, the strut has to be fitted below the arms. This involves considerable risk in the case of heavy lines, since the pole is quite likely to break at this point during heavy gales. The danger can be obviated by fixing an outrigger and stay opposite the junction of the strut and the pole; but the arrangement is unsightly and not very efficient, since the stay-wire is likely to stretch under the enormous stress to which it is subjected. The better plan is unquestionably to employ A or H poles in these cases.

The strut (Fig. 404) consists of a pole of somewhat lighter character than the pole to which it is to be fitted. The upper end of the strut, which should be at least $\frac{1}{2}$-inch thick at the tip, is carefully cut to fit the pole, and two parallel bolts with nuts passing through both secures it in position. The pole itself should upon no account be cut to receive the strut, because, by doing so, it would be weakened at the very point where considerable strength is needed. The cut end of the strut should be painted with tar and creosote—a remark which applies to every cut of every description which is made in a pole, whether for scarfing, arming, or other similar purpose.

At a suitable point the pole and strut are rigidly connected together by a bolt and a length of 1 inch wrought iron tubing. The bolt passes through the strut, spacing tube, and pole. The spacing tube banks against washers upon the under sides of the strut and pole, thus preventing the tightening of the bolt from buckling, or tending to buckle, the strut.

At each side of the pole a galvanized iron washer $3\frac{1}{2}'' \times 2\frac{1}{2}'' \times {}''\frac{1}{4}$ is employed, whilst the inner side of the strut is built up by means of tapered round washers so as to provide a perpendicular surface for the W.I. tube to bed against. Upon the outside leg of the strut a rectangular tapered washer, hollowed to suit the round pole is fitted,

and above this a round tapered washer for the nut of the bolt to bank against.

In the very exceptional cases in which a strutted pole is in such a position that a horseman can ride between the pole and its strut the tie bolt is fitted at least 12 feet above the ground. Also, where a strutted pole or an A-pole has an opening which is not sufficient for cattle to pass through but in which they might possibly get jammed, a vertical guard of creosoted timber 6 or 8 feet long with a pointed tip should be fixed in the centre of the aperture. A similar guard is sometimes required in the space between a pole and the wall where the space is restricted.

A strutted pole has a tendency to lift out of the ground by the sinking of the strut and, in order to prevent this, the pole and strut are cut to receive a couple of stay-blocks, which are secured to them by $\frac{5}{8}''$ bolts and nuts.

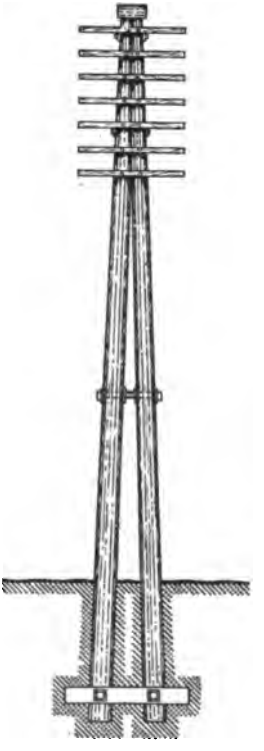


FIG. 405.—An A-pole

A-POLES.

For heavy stresses where a stay cannot be fixed A-poles (Fig. 405) are frequently employed. A long scarfed joint is made, and the two poles secured by a couple of $\frac{5}{8}''$ bolts, a tie-rod and tube, and a wooden block brace or transom. The poles are each reduced by not more than one-third of their diameter, and the cuts are covered with tar and creosote, so forming an air and water tight joint and thus preventing premature decay. The tie-bar and tube are employed, and is fixed half-way down the pole, two round washers being used at the ends of the tube and two hollowed tapered washers against the outsides of the two poles. The transom consists of a block of creosoted wood, 7 or 8 inches square and of suitable length. This produces an extremely

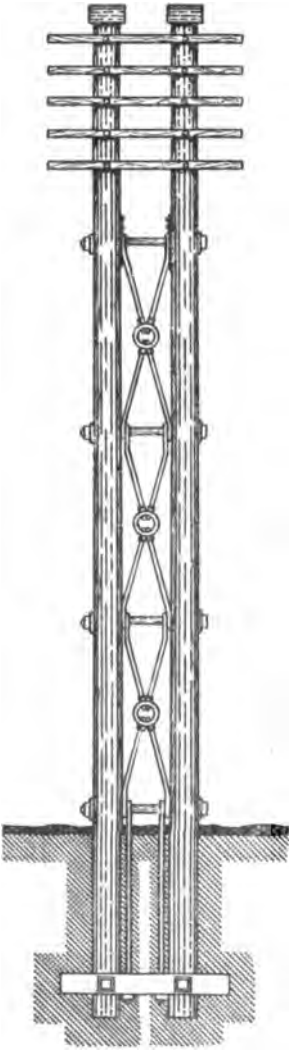


Fig. 406.—An H-pole.

rigid structure, the efficiency of which is still further increased by the bracing effect of the arms which are each secured by two arm bolts, one through each pole. In very exceptional cases it may be advisable to also block the poles at the base and ground line in the manner described in the case of poles in soft ground (p. 681). In ordinary circumstances the spaces between the two poles should not exceed 12 inches at the ground-line, thus giving a scarfed joint 5 or 6 feet long.

In erecting these poles at angles the outer leg should be placed almost vertical, so that when the structure settles the legs shall make equal angles to the normal. It is preferable to err upon the side of having the outer leg vertical than to have the inner one, vertical so giving the outer leg the appearance of a wooden stay!

With A-poles the gradually increasing width of the poles as arms are added soon fixes a limit to the number of wires which the pole will carry, but this difficulty is frequently minimized by the use of 72 inch arms. Of course, two different sizes of arms should not be used upon one pole, on account of the unsightliness of the resulting structure. One earth wire only is required, and this is fixed in the least conspicuous position.

H-Poles.

Where space is available the H-pole, designed by M. F. Roberts, is to be preferred to the A form, since it provides for a larger number of wires. The structure is depicted in Fig. 406, from which it will be seen that the poles are connected together by tie-bolts and tubes together with truss-rods and rings. The object of the arrangement is to secure rigidity, and convert what would otherwise be two independent structures into the equivalent of a lattice girder. The arms each carry six wires, two of which are placed between the two poles. It should be noticed that the lowest tie-bar is connected with the wooden cross-piece, notched at least six inches in, at the base of the poles and that the top tie-bar is provided with large washers to prevent the top truss rods from damaging the poles by abrasion, consequent upon slight lateral motions under wind stress. Two earth wires are invariably fitted, one upon each pole.

Where the number of wires will not exceed 38, *i.e.* 6 arms and two saddle wires, medium poles are employed and the redwood cross-piece or pole brace is 6 feet long by 8 inches square. Above this number, stout poles and a brace $8' \times 8'' \times 8''$ are employed. The poles are 18 inches apart in the clear and the rods and bolts are all of $\frac{3}{4}''$ metal. The truss rods are, however, provided in 3 and 4 feet lengths, so that the trussing may be carried from 6 inches above the ground-line to any required height. All the rods connected to any one ring must be of the same length, and where it is necessary to use sets of both sizes upon one pole the longer rods should be used at the upper part of the structure.

Saddle Wire.

Many lines carry a "saddle" wire supported upon an insulator of the ordinary double-shed type. The arrangement is illustrated in Fig. 407; but in this case the saddle is fitted with a "saddle stay" to prevent canting. This addition is, however, only necessary at angles in the line.

The pole roof employed is of the "cut" type, and is secured by four $3\frac{1}{2}''$ coach screws, which also hold the saddle. At the sides of the pole two hardwood wedges are used for the galvanized hoop-iron saddle stay to bed

against. The stay is secured to the pole by two coach-screws, one upon each side of the pole.

When an A pole is required to carry a saddle wire a hard wood cylindrical pin, termed a trenail, about an inch in diameter is driven through both poles, parallel with the arms and directly below the apex of the roof in such a manner that the coach screws securing the saddle in position shall enter the trenail.

Pole-Steps.

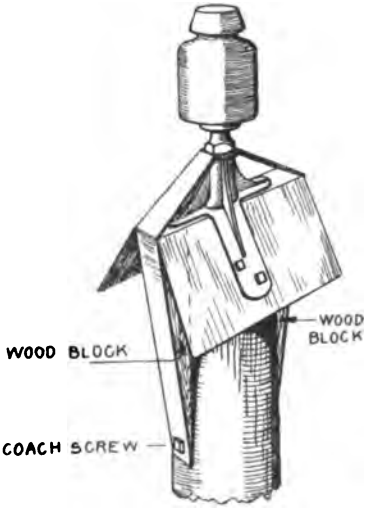


Fig. 407.—A saddle fitted with a stay.

In order to avoid the use of very long ladders and to save climbing it is usual to fit pole-steps upon all long timber. The lowest step is always twelve feet from the ground, so as to render them inaccessible to mischievous persons. The method of fitting the steps will be apparent from a consideration of Fig. 399, three coach screws being employed for securing the steps to the pole. The distance between the steps upon each side of the pole is 2′ 6″ and between two consecutive steps upon opposite sides of the pole 15 inches.

Hook-Guards.

Where a line takes the inside of a curve upon a road, hook-guards are frequently employed to prevent a wire which has become detached from its insulator from overhanging the roadway in such a fashion as to be a source of danger. These guards are fixed beneath the lower flange of the insulator spindle and project above the wire. The device is open to the objection that with any but light

wires it is useless, since a heavy wire at once bends the guard and escapes.

Iron Poles.

It has already been pointed out that the cost of iron poles is several times as much as that of wooden ones, and therefore their use is restricted to the utmost extent. There are, however, cases in which local authorities specially desire the use of iron in preference to wood, and where the streets are of a busy character, or in high-class residential districts, the request is occasionally granted. The diameter of an iron pole is less than that of a wooden pole of the same height and strength. It is scarcely possible to describe a telegraph pole as ornamental, be it of creosoted or painted wood or of iron, but, as with electric tramways and street lighting, it is necessary to sacrifice appearance for the common good.

Iron poles are divided into five classes, designated light, medium, stout, extra stout, and heavy, which are respectively designed to carry 8, 16, 24, 32, and 40 wires, with a maximum height of 45 feet above the ground-line.

The Bullers' pole, which has been adopted by the Post Office, consists of a cast-iron base, into which is fitted the wrought steel pole formed of either three or four tubes jointed together. In every case the first two sections consist of parallel tubes, whilst the last section is generally tapered. Each joint occupies a space of one foot, hence two 11 foot parallel tubes and one 16 foot tapered tube forms a pole 35 feet long (1 foot of the first tube in the socket of the base, 1 foot of second tube within the first, and 1 foot of the third tube within the second). The tubes are interchangeable, and from the fifteen types shown in the first column the various poles detailed in the second may be formed by jointing the tubes as indicated by the third column. The distinguishing figures and letters employed serve merely to correlate the two tables and at the same time to emphasize the general scheme of the design.

DIMENSIONS OF WROUGHT-STEEL TUBES.

Parallel tubes 11 feet long.			Tapering tubes.				
Distinguishing number.	Diameter in inches.	Thickness of metal in inches.	Length in feet.	Diameter in inches, tapering.		Thickness of metal.	Distinguishing letter.
				From.	To.		
1	8¼	⅜	16	6¾	5⅝	7/32	A
2	7 1/16	5/16	16	6 3/16	5⅜	¼	B
3	6¾	¼	16	5¾	4	5/16	C
4	6 3/16	1/16	16	5⅜	4	5/32	D
5	5¾	5/32	16	5	3	3/32	E
6	5⅜	3/32	11	6 1/16	3	3/32	F
			11	5¼	3	1/32	G
			11	5⅛	3	5/32	H
			11	5	3	1/32	I

DETAILS OF IRON POLES.

Type.	Height.	How formed.	Normal carrying capacity.	Length of base.
Light	30 feet	5, 6, I	8 wires	4′ 0″
,,	35 ,,	5, 6, E	8 ,,	4′ 0″
Medium	30 ,,	4, 5, 6	16 ,,	4′ 0″
,,	35 ,,	4, 5, D	16 ,,	4′ 0″
Stout	30 ,,	3, 4, 5	24 ,,	4′ 6″
,,	35 ,,	3, 4, C	24 ,,	4′ 6″
,,	40 ,,	3, 4, 5, 6	24 ,,	5′ 0″
,,	45 ,,	3, 4, 5, D	24 ,,	5′ 0″
Extra Stout	30 ,,	2, 3, 4	32 ,,	5′ 0″
,,	35 ,,	2, 3, B	32 ,,	5′ 0″
,,	40 ,,	2, 3, 4, 5	32 ,,	5′ 0″
,,	45 ,,	2, 3, 4, C	32 ,,	5′ 0″
Heavy	30 ,,	1, 2, 3	40 ,,	5′ 6″
,,	35 ,,	1, 2, B	40 ,,	5′ 6″
,,	40 ,,	1, 2, 3, 4	40 ,,	5′ 6″
,,	45 ,,	1, 2, 3, B	40 ,,	5′ 6″

The carrying capacity is subject to the qualifications that light wires, preferably 70 lb. bronze, 100 lb. copper, or at most 150 lb. copper, wires are employed, and that, since the

FIG. 409.—Method of jointing the wrought-iron tubes.

FIG. 411.—The ornamental sleeve.

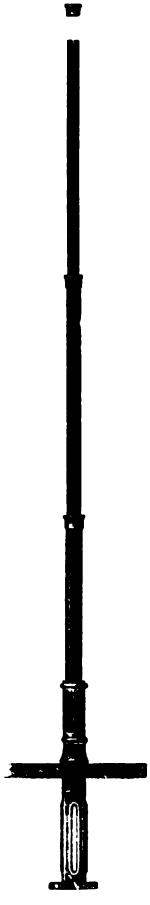


FIG. 408.—An iron pole complete.

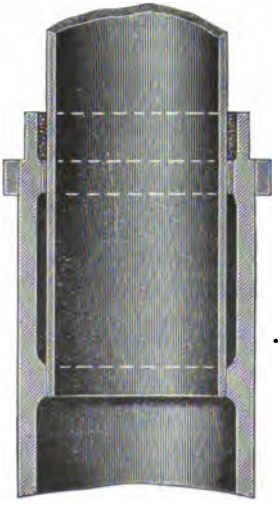


FIG. 410.—Method of fixing the bottom wrought-iron tube in the cast-iron base.

FIG. 412.—The cast-iron base which is embedded in the ground.

positions are usually such that stays cannot be fitted, there shall be no difficult angles.

The joints between the sections of the pole are made by driving on jointing rings, so obviating the necessity for the "leaded" joints which were so conspicuous a feature of the older designs. The cast-iron base (Fig. 412) projects $1\frac{1}{2}$ inches above the ground-line and prevents corrosion of the steel tube whilst giving a securer hold in soft ground. In order to improve the appearance an ornamental sleeve (Fig. 411), which extends 3′ 6″ above the ground-line, is placed above the base and, upon the top of the pole, a wooden finial is fixed.

A complete pole is illustrated in Fig. 408, and, with the aid of the two subsequent tables, the method of forming any of the poles from the 15 types of tube will be quite apparent, the various tubes being interchangeable.

The details of the Chambers' joint between successive tubes are illustrated in Fig. 409, from which it will be observed that the upper end of the tube is split longitudinally and that two wedge-shaped plates are riveted to the inner sides of the tube so as to form a support for the lower end of the upper tube which is cut to fit the fixed plates upon the lower tube. By driving the iron collar or jointing ring downwards the two halves of the split portion of the tube are brought into firm and rigid contact with the upper tube. The method of jointing the lowest tube to the cast-iron base is shown in Fig. 410. The upper portion of the base is shaped to receive the slightly tapered end of the lowest tube and to fit the wedge-shaped ring which is shrunk on to the tube a little higher up.

Another arrangement which has been designed provides for the substitution of an extra stout for a light pole without the necessity of disturbing the pavement. An extra stout base is used, and the diameter of the socket reduced by means of an "adapter" so as to receive a light pole. When, owing to increases in the number of wires, it becomes necessary to substitute an extra stout pole the adapter is removed and the new pole fitted within the base. Of course, a similar arrangement is needed to fill the space between the large sleeve and the light pole.

Bullers' tubular iron arms, of the pattern shown in Fig. 413, are used and are fixed upon the pole by means of

the clips. The 2-wire arms are 20″ long, whilst the 4-wire arms are 44″ in length, and provide for a space of 12″ between the insulator spindle holes. As previously mentioned, a wooden strip is placed over each side of the arm and is held in position by the lower flanges of the insulator spindles.

Where an iron pole is used at the junction of an underground with an open line the wires are taken up the inside of the pole and pass out at the top through a curved ebonite tube of suitable dimensions.

As a conclusion to the subject of iron poles it is necessary to briefly consider the method of erection. The base is set in the ground so that the uppermost portion projects

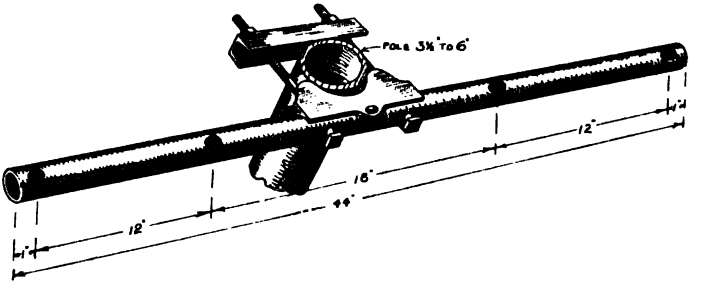


FIG. 413.—Iron arm used upon iron poles.

1½ inches above the ground-line. This brings the projecting flange which carries the ornamental sleeves ½″ below the ground. In some cases the base is fixed upon a concrete foundation by means of bolts let into the concrete, and passing through the flange holes cast in the base, but this is not ordinarily necessary.

The various lengths making up the pole are put together on the ground, the malleable iron rings being driven home and a little thick paint or putty worked into the joints and slots to prevent rust discolouring the subsequent painting. Before the bottom length of tube is jointed to the upper lengths, the ornamental sleeve is placed on it. The two grooves (opposite each other) will be found on the inside of top of sleeve to enable it to slide over the rivet-heads on the bottom tube. With the sleeve in this position the bottom

length of tube is fixed to the upper lengths by the ring as already described. The sleeve is then lashed to the ring joint so that it may be out of the way whilst the pole is being erected.

The various tubes making up the pole having been put together, the bottom end of the pole is placed in the base with the assistance of a derrick or by other suitable means, special care being first taken to clean off the mixture of white lead and tallow from the machined surfaces (both inside and out) forming the bottom joint. The cast-iron sleeve is then lowered into position, and a man ascends to the top of the lower length, which will be about 10 feet from the ground-line, and, by tapping on the jointing ring, drives the ground joint firmly into its seat. If any of the joint rings have worked loose during erection, they also should be driven home. The space round the top of the joint in the base should preferably be filled up with tow and putty, pitch or cement, to prevent water getting into the bottom joint, and the space between the tube and sleeve (at top of sleeve) should also be filled up in the same way to keep the sleeve in position.

When an "adapter" is used, in order to enable a pole to be used temporarily with a base and sleeve larger than its standard, it should be placed in the base after this has been firmly fixed in the ground and the pole then placed into the adapter, the machined surfaces of the adapter and base being first carefully cleaned. The increased space between the bottom tube and top of sleeve is filled up by means of a cast-iron ring which is locked by giving it a quarter turn after the projections on same have passed down the two grooves in the sleeve.

It should perhaps be remarked that the final punning of the ground around the base will enable the pole to be set perfectly upright when the method of erection is as just described. In many cases the various portions of the pole are assembled upon the ground and then erected in precisely the same manner as wooden poles; the only possible objection to this course lies in the strains which the joints have to bear during erection.

In order to dismantle a pole the jointing rings are driven upwards, and the various sections can then readily be separated.

Erection of a Pole.

Having discussed the various materials employed in the construction of a telegraph line it will now be well to consider the erection of the line. The stores are ordered on to various railway goods-stations *en route*, and when received are laid out in positions which will facilitate the actual work. Considerable economies can be effected by giving careful consideration to this matter.

Where space exists the poles are laid out in twos and threes as near to the point at which they are to be erected

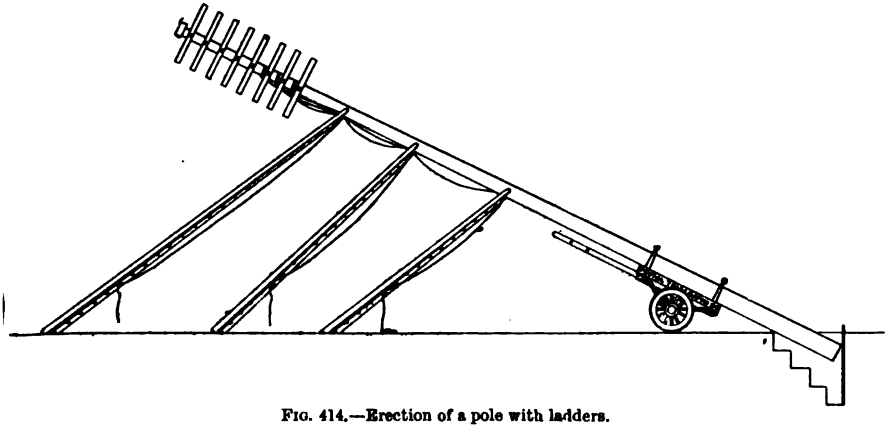


Fig. 414.—Erection of a pole with ladders.

as is possible. This is most economically done by chartering a suitable wagon and horses, and providing sufficient men to safely load and unload the poles. It is unwise to reduce the number of men to the lowest possible limit, owing to the increased risk of accident.

The top end of the pole is raised from the ground on to a trestle, often formed by two crossed arms connected together with an arm-bolt at their centres and with a suitable length of spliced stay wire at their upper extremities. The notches for the arms are then cut in the pole, and the arms fitted with the utmost care. After the preliminary fitting, the arm is removed and the notch well painted with tar and creosote. When all the arms have been permanently fitted

the pole is earth-wired and the pole-roof fixed. Whilst this work has been proceeding the hole will have been dug, and all the members of the party are then employed to raise the pole from the trestle and the pole-cart is run in beneath the pole from the end of, and in the direction of the length of, the pole. The pole is then balanced upon the cart, and is wheeled along to the pole-hole, where the butt is lowered against the heavy wooden plank (see Fig. 393) which is placed against the end of the hole. This completes the first stage of the work.

A suitable number of thin cords or ropes, termed sash-lines, are next fixed to the pole (Fig. 414.) A short ladder is then placed under the pole, and the end of one of the lower sash lines is tied to a rung in order that the ladder may not fall when it is raised from the ground prior to taking a fresh position upon the pole. The ladders are frequently provided with spikes to prevent the ends slipping along the ground when the weight of the pole is encountered. The other end is also equipped, but with an iron band stretching between the sides. This band is suitably roughened to grip the pole, and is free to move so as to bed flat against it. The pole steps fitted upon nearly all long and heavy poles also serve to prevent any possibility of the ladders slipping upwards. Where there are no steps it is sometimes advisable to fix a few upside down, say 4 feet apart, when erecting very heavy poles.

The pole is raised a short distance by the first ladder and a second is then inserted. This ladder takes the weight whilst the first ladder moves to a new position. In similar manner additional ladders are introduced until finally the pole is vertical. The number of ladders employed, like the number of men, varies with the weight and position of the pole. For heavy timber twelve men should be provided. The foreman of the party directs the operations and ensures that only one ladder shall be altered in position at one time.

It should be pointed out that, during the earlier stages of the erection of the pole, the ladders should be splayed out upon either side of the pole so as to prevent the pole from falling laterally. In the later stages the sides of the hole into which the butt sinks deeper and deeper serve to prevent a lateral fall; but in all cases of doubt guy lines should be used with men stationed several yards away.

When the pole is up it is either strutted by a ladder banked beneath an inverted pole step or stayed with a rope connected to a crowbar driven into the ground. The pole is next turned so that the arms are in the correct direction. This may be accomplished by means of an endless loop of wire passing over a coach-screw driven into the pole and a crowbar as lever. A special tool has, however, been designed to meet this requirement.

The pole is carefully packed with large stones upon the sides, and the earth is shovelled into the hole in small quantities, and is thoroughly punned. This operation is of the utmost importance, for upon it largely depends the future security of the line. The post hole should always be as small as possible, and where the pole will be subjected to lateral stress it should be given a set such that the stress will bring it to the vertical, but upon no account should the set exceed the amount necessary for this purpose.

Pole lifters have been used instead of ladders to a very considerable extent, and especially with light poles. The lifters consist of light ash poles furnished with a double pronged fork at the upper end. This fork is thrust into the pole to be erected, and the lifters are used in a manner identical with that previously described in the case of poles erected with the aid of ladders.

Use of Derrick.

Where the scantling is of a long and very heavy character, or where the position in which the pole is to be placed is an awkward one, it is frequently quite impossible to erect it in the manner previously described. Again, it occasionally happens that the pole is too long to be turned round in the road so as to get it into position for erecting in a space, entry, or street, at right angles to the road. There are also cases in which the pole has to be lifted bodily over a wall, building, or other obstruction. These are some of the conditions which render the use of a derrick essential.

It may be pointed out that in confined spaces, or with very long and heavy timber, the use of ladders is attended with some risk. Should a heavy pole come down, due to the ladders slipping, a fatal accident will almost inevitably result, and therefore the use of a derrick is recommended in every case of doubt.

The derrick consists of a short stiff pole, buried to a depth of at least two feet, to which an arm is fixed at the top. Above this arm (Fig. 415) a sling chain is placed round the pole, and to this is attached the treble block end of the main tackle. The pulling end of the 3″ rope (3″ is the circumference of the rope) is passed through a snatchblock hooked on a sling chain at the base of the derrick. In order to prevent this chain from slipping up the derrick when a stress is placed upon the rope, 6″ spikes are driven into the derrick. A couple of crowbars are driven into the ground and connected so that the rear bar forms a stay upon the forward one. To this a smaller set of luff tackle with 2″ rope is attached by means of another sling chain. The double end of the luff tackle is secured to the running end of the main set. The derrick is stayed in at least three, and preferably in four, directions to crowbars driven into the ground. Every hook is moused, *i.e.* bound across, so as to make it impossible for the chain to be jerked out.

The pole is wheeled to the post hole upon the pole cart, and a length of stout timber is placed against the back of the hole in order to avoid any risk of the pole breaking out of the hole during the earlier stages of erection. Four sash lines are attached to the upper part of the pole and are used to resist any tendency towards swinging. Finally the double block of the main tackle is attached to a sling chain fixed just above the centre of gravity of the pole.

The pole is then reared by pulling the running end of the luff tackle. When the blocks of this tackle come together the running end of the main tackle is stoppered by means of a length of rope attached to the snatchblock sling chain. This is accomplished by a very simple yet safe form of tie. The luff tackle is then extended and connected to the main rope close to the snatchblock. In this way the pole is gradually erected.

During the progress of erection a man is stationed at the hole with a punner or rammer with which the butt of the pole is eased down the plank at the back of the hole. As there is a heavy downward stress upon the derrick, it should rest upon a substantial block of wood when the ground is at all soft.

If the work is carried out with care there is no risk of

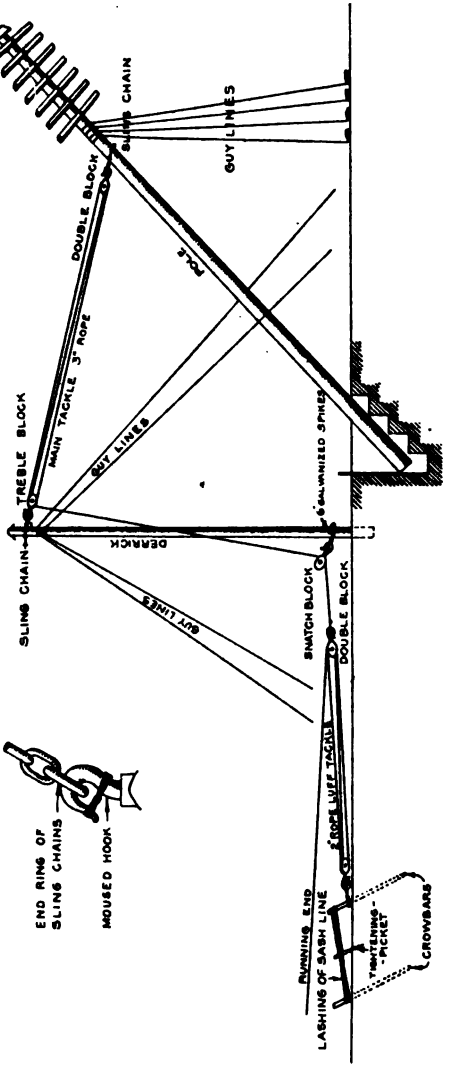


FIG. 415.—Erection of long and heavy poles with a derrick

accident. The following points must, however, receive attention:—

(1) The whole of the tackle should be carefully examined. A small quantity of soldering fluid spilt upon a rope is quite sufficient to reduce its strength to the danger point. Again, ropes must not be allowed to get damp.
(2) The derrick must be of sound, stout timber, and should not be erected too close to the post hole.
(3) When the pole is nearing the vertical position a pull should be exerted against that of the main tackle, so that stress may not suddenly be removed from the derrick. This is necessary to obviate any risk of the relief of the stress from causing the derrick to kick out of its hole.
(4) The foreman should stand by and closely watch the operations, and *under no circumstances whatever should he quit his post of observation to give temporary assistance to the men.*

It is, unfortunately, true that accidents do and will occur, but in most cases they are the results of gross carelessness or of nervousness. In the particular class of work just considered, accidents have occurred through the use of too light a derrick, insufficient stays, and defective ropes. In raising a pole from the ground to the pole cart the men should all be upon the same side of the pole, so that, if it should fall, no one is likely to be caught by it. In the case of heavy poles the cart should be run in from the end and under no circumstances from the sides. The pole should be raised in stages until the cart can be run in from the end of the pole, and at every stage of the operation it must be impossible for the pole to fall flat upon the ground. The same method should be adopted in the reverse order when unloading poles from the cart. When running the loaded pole cart along the road the man deputed to steer should always be at the back of the cart and the remainder of the party should pull by means of sash lines. When removing poles a ladder should be fixed both at the front and at the back of the pole before digging out is commenced, and under no circumstances should any one ascend the pole after the work of digging out has been commenced. All

tools or other materials should be pulled up, or lowered down, the pole with an endless line passing over an arm upon which the outside insulator bolt has been placed in position. Considering the huge amount of work done by the Post Office the number of accidents is comparatively small, and no doubt compares very favourably with the number in any other branch of engineering. If the italicized sentence under paragraph 4 upon the previous page were more strictly observed there would be still fewer accidents. There is room for improvement in this respect, and the writer, therefore, submits these remarks for the consideration of those actually engaged in the construction of aërial lines.

Wiring.

The operation of running the wires next calls for attention. A coil of wire is placed upon the "drum barrow," which consists of a drum carried by a vertical axis mounted upon a light form of barrow. A brake is provided so that the revolution of the drum may be checked when necessary. The outer end of the coil of wire is then taken over the arms upon which it is to be erected. For this purpose light ladders are used and not pole-climbers, since the climbers score the poles with a series of unsightly marks. In fact, many gangs are not allowed to have even a single pair of climbers amongst their tools for this very reason.

The wire having been passed over the arms of about 8 poles is then pulled up by a suitable number of men, whilst the final adjustment is made by means of a tension ratchet and vice.

The tighter the wire is drawn up the smaller is the sag or dip, and therefore the smaller is the risk of contact. Upon the other hand the stress upon the wire may be made so great that the wire is liable to break. The ratio between the breaking stress of the wire and the maximum tension to which it is subjected is termed the "factor of safety." The factor of safety is least during very cold weather, when the wire has contracted to the maximum extent, and is greatest during very hot weather. For instance, a 150 lb. copper wire, with a stress of 120 lbs. upon a 60 yard span at 22° F. would have expanded sufficiently to reduce the stress to 36 lbs. at 100° F. The practice is to pull up the

wires to a tension such that under the worst conditions it shall not exceed one quarter of their breaking stress. In other words a factor of safety of four at low winter temperature is always allowed. Ordinary winter temperature is usually about 40°, average summer temperature 60°, and that of a very hot day about 75°.

FIG. 416.—Light draw tongs.

For straining the wire to the required degree, either tension ratchets and draw tongs or draw vices are employed. In the case of light copper wires the tension ratchet is of the

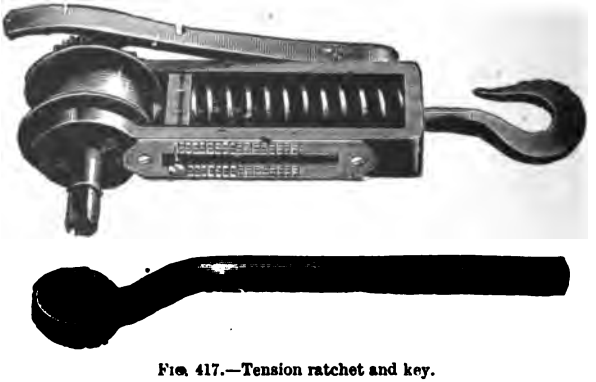


FIG. 417.—Tension ratchet and key.

type shown in Fig. 417, the draw tongs being illustrated in Fig. 416. The two sides of the draw tongs are identical save that the diameters of the longitudinal grooves in the fixed block and the lever are, upon one side, suitable for gripping 70, 100, or 150 lb. wires, whilst those upon the other side are designed for 200 lb. wires, the object so gained being the avoidance of a multiplicity of different tools.

The line wire is gripped by the tongs, which are hooked on to the tension ratchet, the latter being attached to the arm of the pole by means of a length of iron wire which is also passed through the hole in the drum of the ratchet. By turning the ratchet-drum the wire is pulled up and the tension indicated upon the scale at the side of the instrument. The process is so obvious that further description is scarcely necessary.

In wiring a new line the top or first wire dealt with is carefully strained by using tension ratchets which have very recently been checked for accuracy. The remaining

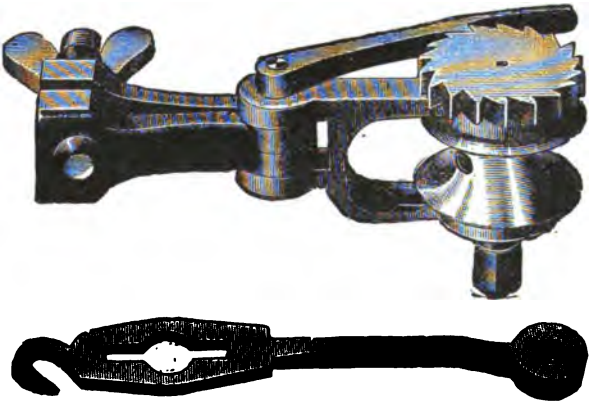


FIG. 418.—Steel draw vice and key.

wires are then pulled up to accord with the first by judging the dip by the eye. In the case of twisted telephone loops the accuracy of the adjustment may readily be judged by observing if the two wires of every pair appear to cross exactly at the centre of the span.

The draw-vice shown in Fig. 418 is very frequently employed in connection with iron wires, especially where additional wires have to be run and the stress is adjusted by observation of the dip.

For heavy gauge copper wires a larger form of tension ratchet and a specially designed draw-vice are employed, but the general principles involved are identical.

When the poles have been erected in wet weather it is

desirable to delay the wiring as long as possible in order that the ground may have time to consolidate.

Sags and Stresses.

The stress which should be put upon the wires when erected now requires to be considered. The smaller the dip the less liability to contact, whilst the greater the dip the less will be the chance of the wire snapping. In practice the wire is pulled up to one quarter of its breaking weight if erected at low winter temperature, *i.e.* 22° F.

The relations between the length of the span, weight of wire and stress are given by the following formulæ* :—

$$d = \frac{l^2 w}{8s}, \quad s = \frac{l^2 w}{8d}$$

where l = length of span in feet;
w = weight of one foot of the wire;
s = stress in lbs.;
d = sag or dip in feet.

From these formulæ the following facts may be deduced :—

1. The dip in feet is equal to the square of the length of the span in feet multiplied by the weight of the wire per foot, divided by eight times the stress in pounds.
2. The stress in pounds is equal to the square of the length of the span in feet multiplied by the weight of the wire per foot divided by eight times the dip in feet.
3. With a given length of span and a line wire of given material the stress is directly proportional to the weight per mile of the wire.
4. The dip of wires of different gauges in a given length of span varies with the material of which the wire is composed, but not with the gauge.

* The proof of these formulæ is beyond the scope of this volume. The curve in which the wire hangs is a catenary, but may be assumed to be a parabola, without serious error. For proof see Prof. Perry's *Calculus for Engineers*, page 62.

Since the breaking weight of a wire is directly proportional to its sectional area, it is also directly proportional to the weight of the wire per mile. Hence the dip of a wire varies with the material of which it is composed, but not with its gauge. This applies to any temperature, so that wires of differing gauges but of the same material may be erected upon a line without risk of contact, since the dip will be the same at every temperature.

In erecting iron and copper wires upon the same pole the effects of their differing coefficients of expansion are minimized by keeping the length of the span to 80 yards or under, but where this is impossible the stress tables are, to a small extent, departed from. It is preferable to run the iron wires at the top and the copper wires below for two reasons, firstly, because the iron telegraph wires are least subject to alteration by the addition of new circuits, and secondly, because the risk of contact is reduced.

The stress which is put upon a wire depends upon the material of which the wire is composed, the length of the span and the temperature. Every gang is supplied with a thermometer in order that the actual temperature of the wire itself during erection may be accurately known. The length of the span is readily measured by pacing or judging the distance. With this information the stress to be put upon the wire is obtained from tables which have been previously prepared.

Reference to the tables will show that changes of temperature have a much greater effect upon the stress of wires in short than in long spans, and consequently great care is necessary in the regulation of the wires. Moreover, it may be observed that whilst at any particular temperature the stresses are equal in two adjoining spans of different lengths they will be unequal when the temperature changes. This difference is compensated by a slight deflection of the pole, and in running wires over a number of poles it is only necessary to consider the average length of span when consulting the stress tables. At angles where the poles have been given a slight set an extra stress of 10 or 20 per cent. is sometimes necessary to compensate for the subsequent deflection of the pole.

SAGS FOR COPPER AND IRON WIRES AT VARIOUS TEMPERATURES WHICH PROVIDE FOR A FACTOR OF SAFETY OF 4 AT 22° FAHR.

Temperature in Degrees Fahr.	Sags for Various Spans.									
	Copper Wire.					Iron Wire.				
	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
22	0 8	0 11 5/8	1 3 5/8	1 8 3/8	2 1 7/8	0 9 1/2	1 1 5/8	1 6 1/2	2 0 1/4	2 6 5/8
25	0 9 7/8	1 2 3/4	1 5 3/4	1 10 1/2	2 4	0 10 3/4	1 2 3/8	1 7 1/8	2 1 1/2	2 8
30	1 0 1/2	1 4 1/4	1 8 5/8	2 1 5/8	2 7 1/8	1 0 1/2	1 4 1/4	1 9 1/4	2 3 1/2	2 10
35	1 2 3/4	1 6 3/8	1 11 1/4	2 4 3/8	2 10	1 2	1 6 1/2	1 11 5/8	2 5 5/8	2 11 7/8
40	1 4 1/2	1 8 3/4	2 1 5/8	2 6 7/8	3 0 5/8	1 3 1/2	1 8	2 1 1/4	2 7 1/8	3 1 3/4
45	1 6 1/4	1 10 3/4	2 3 3/4	2 9 1/4	3 3 1/4	1 4 3/4	1 9 3/8	2 2 7/8	2 8 7/8	3 3 1/2
50	1 7 3/4	2 0 3/4	2 5 3/4	2 11 3/8	3 5 1/2	1 6	1 10 7/8	2 4 1/4	2 10 3/8	3 5 1/8
55	1 9 3/8	2 2 1/2	2 7 7/8	3 1 3/8	3 7 3/4	1 7	2 0 1/2	2 5 3/4	2 11 7/8	3 6 3/4
60	1 10 1/2	2 3 3/8	2 9 1/4	3 3 1/4	3 10	1 8 1/8	2 1 1/4	2 7	3 1 3/8	3 8 1/4
65	1 11 3/4	2 5 1/4	2 11	3 5 1/4	3 11 3/4	1 9 1/8	2 2 1/2	2 8 3/8	3 2 7/8	3 9 3/4
70	2 0 7/8	2 6 5/8	3 0 1/2	3 7	4 1 3/4	1 10 1/8	2 3 1/2	2 9 1/2	3 4 3/8	3 11 1/4
75	2 2	2 8	3 2 1/8	3 8 5/8	4 3 5/8	1 11	2 4 3/8	2 10 3/4	3 5 7/8	4 0 3/8
80	2 3 1/8	2 9 1/4	3 3 1/2	3 10 1/4	4 5 3/8	1 11 7/8	2 5 3/8	2 11 7/8	3 6 3/8	4 2
85	2 4 1/4	2 10 3/8	3 5	3 11 7/8	4 7 1/8	2 0 3/4	2 6 3/8	3 1	3 7 1/4	4 8 1/4
90	2 5 1/4	2 11 5/8	3 6 1/4	4 1 3/8	4 8 3/4	2 1 5/8	2 7 3/8	3 2 1/8	3 9 1/8	4 4 5/8
95	2 6 1/4	3 0 3/4	3 7 5/8	4 3 3/8	4 10 3/8	2 2 3/8	2 8 3/8	3 3 1/4	3 10 1/4	4 5 7/8
100	2 7 1/8	3 1 7/8	3 9	4 4 3/8	5 0	2 3 1/8	2 9 3/8	3 4 1/8	3 11 3/8	4 7 1/8
Poles per Mile.	35	29	25	22	19½	35	29	25	22	19½

The sag varies with the material and not with the gauge.

STRESSES TO BE OBSERVED IN ERECTING COPPER WIRES AT VARIOUS TEMPERATURES.

Temperature in Degrees Fahr.	Stresses in lbs. for Various Spans in Yards.																				Temperature in Degrees Fahr.
	150 lbs. per Mile. (97 Mils Diameter, No. 12½ S.W.G.)					200 lbs. per Mile. (112 Mils Diameter, No. 11½ S.W.G.)					400 lbs. per Mile. (158 Mils Diameter, No. 8 S.W.G.)					600 lbs. per Mile. (193 Mils Diameter, No. 6 S.W.G.)					
	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
22	120	120	120	120	120	160	160	160	160	160	320	320	320	320	320	480	480	480	480	480	22
25	96	102	106	109	111	129	136	142	145	148	258	272	284	290	296	386	409	425	436	444	25
30	76	84	91	96	99	102	113	121	128	133	204	226	242	256	266	306	338	364	383	399	30
35	65	74	81	86	91	87	98	108	115	122	174	196	216	230	244	262	295	323	346	365	35
40	58	66	73	79	84	77	88	96	106	113	154	176	192	212	226	232	265	294	318	338	40
45	52	61	68	74	79	70	81	90	98	105	140	162	180	196	210	211	243	271	296	317	45
50	48	56	63	69	75	65	74	84	92	100	130	148	168	184	200	194	223	253	277	299	50
55	45	53	59	65	71	60	70	79	87	94	120	140	158	174	188	182	211	238	262	284	55
60	42	50	56	62	67	57	66	75	83	90	114	132	150	166	180	171	200	226	250	270	60
65	40	47	53	59	65	54	63	71	79	86	108	126	142	158	172	162	189	214	238	260	65
70	38	45	51	57	62	51	60	68	76	83	102	120	136	152	166	153	181	205	229	249	70
75	37	43	49	55	60	49	58	66	73	80	98	116	132	146	160	147	173	197	220	240	75
80	35	41	47	53	58	47	55	63	71	77	94	110	126	142	154	141	166	190	212	232	80
85	34	40	46	51	56	45	53	61	68	75	90	106	122	136	150	136	160	183	205	225	85
90	33	39	44	49	54	44	52	59	66	73	88	104	118	132	146	131	155	177	199	218	90
95	32	37	43	48	53	42	50	57	64	71	84	100	114	128	142	127	150	172	192	212	95
100	31	36	42	47	52	41	48	56	62	69	82	96	112	124	138	123	146	167	186	207	100
Poles per Mile.	35	29	25	22	19½	35	29	25	22	19½	35	29	25	22	19½	35	29	25	22	19½	Poles per Mile.

STRESSES TO BE OBSERVED IN ERECTING IRON WIRES AT VARIOUS TEMPERATURES.

Temperature in Degrees Fahr.	Stresses in lbs. for Various Spans in Yards.									
	200 lbs. per Mile. (121 Mils Diameter, No. 10½ S.W.G.)					400 lbs. per Mile. (171 Mils Diameter, No. 7½ S.W.G.)				
	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.	50 yds.	60 yds.	70 yds.	80 yds.	90 yds.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
22	135	135	135	135	135	270	270	270	270	270
25	120	124	127	128	130	239	247	253	256	259
30	103	110	115	119	122	205	219	230	238	243
35	91	100	107	112	115	182	199	213	223	230
40	83	92	99	105	110	165	184	198	210	219
45	77	86	94	99	105	153	172	187	199	210
50	72	81	89	95	101	143	161	177	190	201
55	67	77	85	91	97	134	153	169	182	194
60	64	73	81	88	94	127	146	162	175	187
65	61	70	78	85	91	121	139	155	169	181
70	58	67	75	82	88	116	134	149	163	175
75	56	64	72	79	85	111	129	144	158	170
80	54	62	70	77	83	107	124	140	153	165
85	52	60	68	75	81	103	120	135	149	161
90	50	58	66	73	79	100	117	132	145	157
95	48	56	64	71	77	97	113	128	142	154
100	47	55	63	69	75	94	110	125	138	150
Poles per Mile.	35	29	25	22	19½	35	29	25	22	19½

Factor of safety of 4 at 22° Fahr. for all wires.
The stress varies with both the gauge and the material.
The stress for 100 lb. (No. 14) copper wire is half that for 200 lb.
The stress for 800 lb. (No. 4½) copper wire is double that for 400 lb.
The stress for 70 lb. bronze is the same as 100 lb. copper wire.
The stress for 300 lb. copper wire is half that for 600 lb.

The tables shown above have been calculated from the formulæ given below, all of which may readily be deduced from those given upon page 712.

$$d_1 = \sqrt{d^2 + l^2 (T \times \tfrac{3}{8} K)}$$

$$s_1 = s \frac{d}{d_1}$$

$$d = \sqrt{\frac{3l(L-l)}{8}}$$

$$L = l + \frac{8d^2}{3l}$$

$$d_1 = \sqrt{\frac{L(1+KT)-l}{L-l}}$$

where l = length of span;
d = dip at 22° F.;
d_1 = dip at higher temperature;
s = stress at 22° F.;
s_1 = stress at higher temperature;
w = weight of wire per unit length;
L = length of wire in span;
T = difference of temperature;
K = coefficient of expansion;

K for copper = ·00000683 per degree Fahrenheit;
„ iron = ·00000956 „ „

Stresses upon Stays.

In order to decide the class and number of stays required, it is necessary to calculate the stresses to which they will be subjected. As an example, assume that a terminal pole carries four 200 lb. wires, with its resultant point 24 feet from the ground, and that 7 feet is available for the spread of stay. The conditions are shown in Fig. 419, and it is required to know whether one stay is sufficient, and whether $\frac{4}{8}$ or $\frac{7}{8}$ wire should be used. The factor of safety for stays is the same as for line wires, viz. 4.

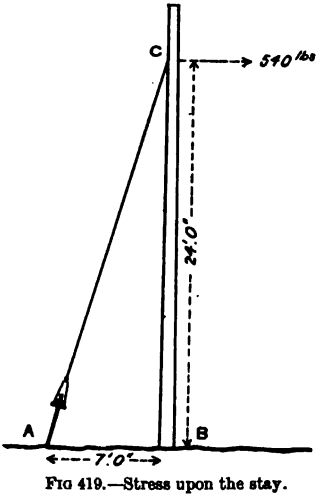


Fig 419.—Stress upon the stay.

The horizontal stress is obtained by multiplying the number of wires by the maximum stress which results at

low winter temperature; in the present case 4×135 lbs. $= 540$ lbs.

In order to solve this problem a knowledge of the following well-known theorem in mechanics is required :—*If three forces acting at a point be in equilibrium they can be represented in magnitude and direction by the sides of any triangle which is drawn so as to have its sides respectively parallel to the directions of the forces.** From this statement it will be seen that the lengths of the three sides of the triangle are proportional to the forces acting in each direction, hence :—

$$A\,B : A\,C :: 540 : \text{stress on stay.}$$

Since $A\,B\,C$ is a right-angled triangle :—

$$A\,C = \sqrt{\overline{A\,B}^2 + \overline{B\,C}^2}$$

$$A\,C = \sqrt{7^2 + 24^2} = 25 \text{ feet}$$

$$\therefore \text{ Stress on stay} = \frac{25}{7} \times 540 = 1930 \text{ lbs. approx.}$$

The breaking stress of $\frac{7}{8}$ stay wire is from 87 to 91 cwts. or say 10,000 lbs.

$$\text{Factor of safety on a } \tfrac{7}{8} \text{ stay} = \frac{10{,}000}{1930} = 5 \text{ approx.}$$

With a $\frac{4}{8}$ stay the factor of safety would be about 3, which is hardly sufficient.

The force tending to drive the pole into the ground is in the same ratio to the horizontal stress as the height of the resultant is to the spread. In the above case the force is therefore :—

$$\frac{24}{7} \times 540 = 1850 \text{ lbs.},$$

or rather less than the stress upon the stay.

Another example of the calculation of the stress upon stays is given in order to make the principle quite clear. The pole illustrated in Fig. 420 carries thirty-two 100 lb. copper wires upon 8 arms with two stays fitted as shown.

* Vide *Elements of Statics and Dynamics*, by S. L. Loney, or any other work on mechanics.

First stay.

Total horizontal stress $= 16 \times 80 = 1280$ lbs.

Length of stay $= \sqrt{30^2 + 16^2} = 34$ feet

Stress on stay $= \frac{34}{16} \times 1280 = 2720$ lbs.

Factor of safety on $\frac{7}{8}$ stay $= \frac{10{,}000}{2720} = 4$ approx.

This may be regarded as satisfactory.

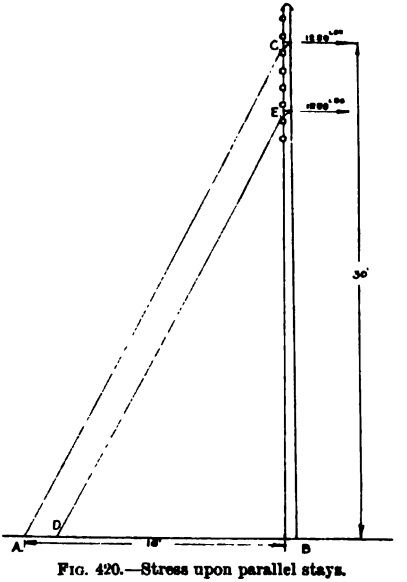


FIG. 420.—Stress upon parallel stays.

Second stay.

Since $D\ E$ is parallel to $A\ C$ the triangles of $A\ C\ B$ and $D\ E\ B$ are similar, therefore the ratio of $E\ D$ to $D\ B$ is the same as that of $C\ A$ to $A\ B$. The horizontal stress is also the same, therefore :—

Stress on $D\ E$ = Stress on $A\ C$
= 2720 lbs.

Factor of safety on $\frac{7}{8}$ stay = 4 approx.

Where the spread of a stay or stays upon a terminal pole

is made equal to the height at which they are attached, the combined stays should contain twice as many strands as there are 400 lb. line wires carried by the pole. For terminal poles the spread should, if possible, equal the height at which the stay is attached, in which case the stress upon the stay is $\sqrt{2}$ × the horizontal stress.

At every angle in a line the pole at which the angle occurs is subjected to a horizontal stress tending to pull the pole over in a direction which would eliminate the angle. The calculation of the value of this stress is necessary to decide the kind and number of stays required.

The distance which the angle pole is out of line with its immediate neighbours is readily observed or measured, and this, with the length of the span and the number and class

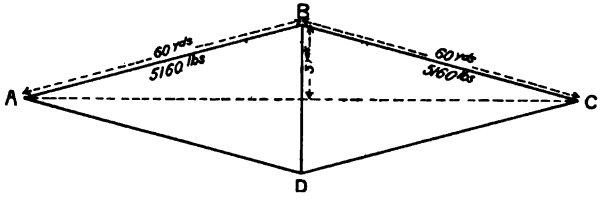


FIG. 421.—Stress upon stay due to an angle in the line.

of wires carried, provides the information necessary for calculating the horizontal stress at the resultant point.

The solution of this problem requires that the following theorem in mechanics should be known :—*If two forces, acting at a point, be represented in magnitude and direction by the two sides of a parallelogram drawn from one of its angular points, their resultant is represented both in magnitude and direction by the diagonal of the parallelogram passing that angular point.**

Example.—A line of 40 ft. poles carries twelve 400 lb. iron and sixteen 150 lb. copper wires. If the pole at an angle is 3 yards out of line, the length of the span upon each side being 60 yards, what stays will be required assuming that

* *Vide.—Statics and, Dynamics*, by S. L. Loney, or any work upon mechanics. The theorem may be proved experimentally or theoretically deduced from Newton's laws of motion.

12 ft. is available for the spread of the stay? (Figs. 421 and 422).

Total stress acting upon each side of angle pole $= 12 \times 270 = 3240$
$16 \times 120 = 1920$
5160 lbs.

The diagonal $B\,D$ = 6 yards.

Since $A\,B\,C\,D$ represents a parallelogram of forces:—

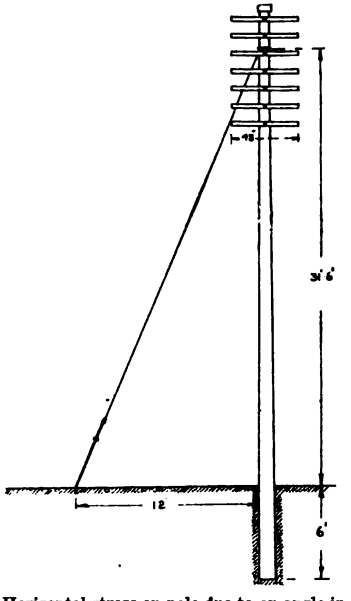


FIG. 422.—Horizontal stress on pole due to an angle in the line.

Length of $A\,B$ or $B\,C$: Length of $B\,D$ :: stress $A\,B$ or $B\,C$: stress $B\,D$.

i. e. 60 : 6 :: 5160 : Horizontal stress.

$$\therefore \text{Horizontal stress} = \frac{6}{60} \times 5160 = 516 \text{ lbs.}$$

The approximate position of resultant point is upon the third arm, *i. e.* 31′ 6″ above the ground-line. (Assuming that the stress upon the third arm acts directly upon the

stay, there is a stress of 8 × 270 lbs. balanced by a stress of 16 × 120 lbs. respectively above or below the resultant point.)

$$\therefore \text{ Length of stay } = \sqrt{31{\cdot}5^2 + 12^2} = 33{\cdot}7 \text{ ft.}$$

$$\text{Stress on stay } = \frac{33{\cdot}7}{12} \times 516 = 1449 \text{ lbs. approx.}$$

$$\text{Factor of safety on } \tfrac{7}{8} \text{ stay } = \frac{10{,}000}{1449} = 7 \text{ approx.}$$

If it is certain that additional wires will not, at any future time, be added to the line a $\frac{4}{8}$ stay would suffice.

Where the two spans upon either side of the angle pole are unequal the semi-diagonal must be measured by taking a point on the longer span equal to the shorter as indicated in Fig. 423. Here the span is 40 yards on one side and 60

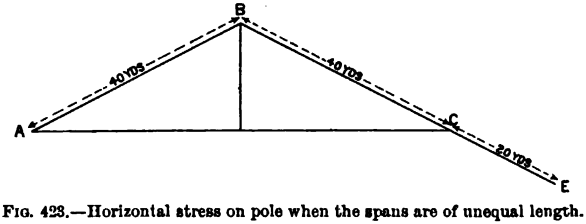


FIG. 423.—Horizontal stress on pole when the spans are of unequal length.

upon the other. Since the stresses in the two spans are the same it will be obvious that they are represented by *AB* and *BC* and not by *AB* and *BE*.

FACTOR OF SAFETY OF AN OPEN LINE.

The stability of a line of telegraphs depends upon its ability to withstand the transverse stress exerted upon it by wind pressure. No line is considered safe unless there is a factor of safety equal to at least 10. The pressure which is exerted by the wind varies as the square of its velocity. If the pressure per square foot at a velocity of 30 miles per hour is 4·428 lbs., at 60 miles per hour a pressure of 17·712 lbs. will result. At 100 miles per hour the pressure is 49·2 lbs., but this is a condition rarely met with. Experience has shown that for telegraph lines having a

resultant about 20′ from the ground 17 lbs. per square foot may be taken as the maximum wind pressure.

The stress resulting from wind pressure may be regarded as acting at the resultant point, and if, therefore, the effective exposed area is multiplied by 17 the transverse horizontal stress in lbs. will be obtained.

The horizontal stress in cwts., which must be applied at the resultant point upon a telegraph pole in order to break it, may be found from the following formula :—

$$W = \frac{4{\cdot}7\ r^3}{l} K$$

where W = horizontal stress in cwts. ;
r = radius of pole in inches ;
l = height of resultant above the ground-line in inches ;
K = coefficient of rupture ;
11·63 for Norway round red fir ;
11 for pitch-pine ;
7·23 for red pine tested in whole balks.

Notes :—

(1) The wind pressure exerted upon a round wire or pole is equal to two-thirds of the pressure which would be exerted upon a flat surface of equal length with a breadth equal to the diameter of the wire or pole.

(2) The force exerted upon each pole is equal to that exerted upon the whole of the wires for a distance of half a span upon each side of the pole.

Example.—A line carrying ten 400 lb. iron wires with a resultant 20′ above the ground-line and with 60 yard spans has poles with a diameter of 10 inches at the ground line. Is the line safe ?

Area of wires two half spans each 30 yards.

Effective area of wires—

$$\frac{(60 \times 36) \times (\frac{2}{3} \text{ of } {\cdot}171) \times 10}{144} = 17{\cdot}1 \text{ sq. ft.}$$

Horizontal stress at resultant = 17·1 × 17 = 291 lbs.

Wind pressure on the pole itself.

Assuming that the pole tapers from 10″ at the ground line to 6″ at the top, and taking the length above the ground line as 22′ :—

Equivalent area of pole $= 22 \times (\frac{2}{3}$ of $\frac{8}{12}) = 9{\cdot}\dot{7}$ sq. ft.
Total wind pressure $= 9{\cdot}\dot{7} \times 17 = 166$ lbs.

But this force should be regarded as acting at a point half-way (11′) up the pole, since its moment varies from nothing at the ground-line to its average value in the centre and to its maximum value at the top of the pole.

The horizontal stress at the resultant point 20′ above the ground is therefore :—

$$\tfrac{11}{20} \times 166 = 91 \text{ lbs.}$$

Total horizontal stress $= 291 + 91 = 382$ lbs.
$= 3{\cdot}41$ cwts.

Breaking stress of pole $= \dfrac{4{\cdot}7 \times 5^3 \times 11{\cdot}63}{20 \times 12}$
$= 28{\cdot}5$ cwts.

Factor of safety $\dfrac{28{\cdot}5}{3{\cdot}4} = 8$ approx.

It will be useful to consider one other problem involving both static and kinetic stresses.

Example.—An angle pole 10 inches in diameter is two yards out of line with 60 yards' span upon either side. If the pole carries twenty 150 lb. copper wires with its resultant 20 feet from the ground-line, will a stay be necessary?

Horizontal stress due to angle in line $= \frac{4}{60}$ of 20×120 lbs.
$= 1{\cdot}4$ cwts.

Effective area of wires $= \frac{2}{3} \times {\cdot}097 \times 20 \times 60 \times 36$ sq. ins.
$= 19{\cdot}4$ sq. ft.

Wind pressure (wires) $= 19{\cdot}4 \times 17$ lbs.
$= 3$ cwts.

Wind pressure (pole) $= 1$ cwt. (say).

Total horizontal stress static + kinetic $= 5{\cdot}4$ cwts.

Breaking stress of pole $= \dfrac{4{\cdot}7 \times 5^3 \times 11{\cdot}63}{20 \times 36}$
$= 28{\cdot}5$ cwts.

Factor of safety $= \dfrac{28{\cdot}5}{5{\cdot}4} = 5$ approx.

Hence a stay should be employed.

Renewals and Alterations.

When it is necessary to renew the poles upon a line care must be taken to prevent interruptions to the circuits working upon the route. One method by which this work is carried out consists in using two ladders as temporary poles. The wires upon each side of the pole are unbound and attached to an insulating strip fixed to a stout ladder upon each side of the pole. These ladders are then drawn

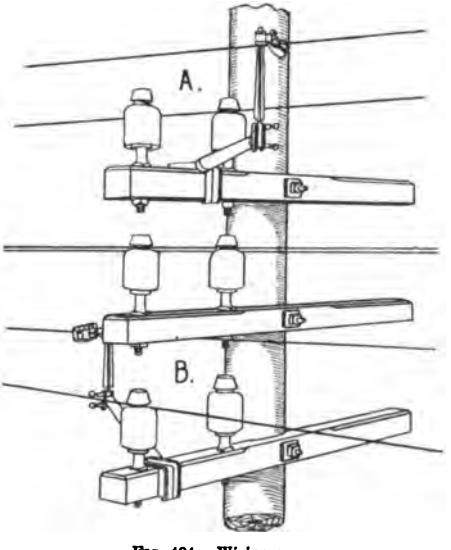


Fig. 424.—Wiring arms.

outwards and temporarily stayed to bars driven into the ground. This leaves a wide gap between the wires upon either side of the pole, which can then be lowered and the new one erected in the ordinary way.

The renewal of the wires upon a route may be effected with the aid of wiring arms fixed upon the arms of the poles. For the renewal of straight wires the arms are fixed as shown at *A* (Fig. 424) for inside, and as shown at *B* for outside wires, but as will be seen from the sketch they are capable of motion to any desired position between the

insulators. The new wire is run through the pulleys and pulled up to approximately the correct tension. It is then transferred to the insulators and the old wire placed in, and finally drawn through, the pulleys on to a drum barrow. In this way it is possible to avoid interruptions to the circuit concerned and also to other circuits upon the poles, the wooden portion of the extension arm being relied upon to maintain a sufficient degree of insulation. There is a considerable advantage in running the new wire through pulleys instead of dragging it over the arms, and this is especially so in the case of copper wire. It may be added that a somewhat similar method is adopted in running and renewing twisted telephone wires, but in this case the arrangements are a trifle more complex.

In special cases of difficult and complicated re-arrangements a special cable, termed an interruption cable, is sometimes employed. These cables are slung upon the poles, and the wires to be renewed are joined through the cable before being cut away, and the new wires are cut in before the interruption cable is cut out. If these operations are carefully performed interruptions need not occur —the guiding principle being never to cut any wire until it has been joined through the cable.

In making a diversion of a line between any two points interruptions are avoided by erecting the new section and allowing the wires to work through both the old and the new lines in parallel. Finally the old line is cut away, but this is not done until the circuits are through upon the new section.

It goes without saying that temporary stays are frequently needed whilst the alterations are in progress. Usually they are provided by driving a crowbar into the ground and connecting it to the pole by one or more 400 lb. iron wires with draw-tongs inserted to tighten the stays.

Surveying for Open Lines.

When it has been decided that a telegraph line shall be erected between two given points, the first work to be done is to decide upon the route to be followed—a matter upon which too much thought can scarcely be bestowed. The possible routes can at once be ascertained by con-

sulting an ordnance map, and, other things being equal, the shortest one is chosen. Generally speaking, there are two or three alternative routes which could be used in the case of a long line, and the final decision is very frequently due solely to the facilities which the roads offer for the erection of stays and for access by the linemen. Again the probable lateral extensions of the line should receive consideration. This preliminary survey is best made by cycling or driving over the various routes, and any special difficulties which are likely to be encountered are noted.

Having selected the route, a detailed survey is made in order to fix the exact positions and lengths of the poles and also to estimate the cost of the work. At the same time the method of laying out the stores and means of cartage are carefully considered. Also, a note is taken of all the wayleave consents which are required. This work should be done with the utmost care and full notes of the decisions arrived at should be made, so that the foreman entrusted with the work can readily be given the fullest possible details of the manner in which the work is to be carried out. Frequently a considerable period elapses between the preparation of the estimate and the actual carrying out of the work, and therefore the value of accurate and full notes will be quite apparent. All the particulars enumerated can readily be entered in a Survey Book of the form shown below :—

State here the Locality, Town, Village, Bridge, or Landmark, by which the spot to which the first entry relates can generally be identified. _____

No.	Distance in Yards.	Right or left.	Position of Pole.	Description of pole.	Stay or Strut.	Arm saddle or bracket.	Insulator.	Special fittings.	Remarks, consents, etc.

In fixing the positions of the poles it must be remembered that during gales the wires are blown out laterally to a distance almost equal to their dip, and therefore trees must be given as wide a berth as possible. Where the level of the road changes rapidly it is desirable to keep the

height of the line fairly uniform. In any case, the heights of the poles must not vary sufficiently to produce an upward pull upon an intermediate pole. This is readily calculated by working out the dip for a span without the intermediate pole. If the pole is too short to reach the lowest point of the wire then there will be an upward pull upon the intermediate pole.

Where the wires cross over buildings chimneys should be avoided, as the effect of the heat and smoke upon the wires is of a most deleterious character. Again, poles should not be placed in positions in which well-water is likely to be contaminated by the creosote, and in all cases of suspicion where there is no possibility of avoiding it poles in which the creosote has dried should be selected.

Long slanting road crossings should be avoided—in fact, the road should be crossed as seldom as possible, but where this is essential the wires should be terminated (upon P.O. terminal insulators) at either side.

Where a long stretch of road is visible it is advisable to make the angles between the successive poles and their stays and struts as nearly uniform as possible, since this course improves the general appearance of the line.

In order to limit the range of damage due to the collapse of a line, by reason of snow accumulations, or the fall of a tree across the line, double longitudinal stays are provided at intervals of about a quarter of a mile. These two stays are fixed in the line of the wires and serve to support the pole should a breakdown occur upon either side. This device is applied wherever it is possible, but unfortunately there are many cases in which the stays would seriously obstruct the road.

A single longitudinal stay is required at points where the wires change in gauge in order to balance the difference in the stresses upon either side of the pole.

In the case of small bends in the line no special provision is necessary, but where the turn is sharp, it is sometimes found that the inner wires in leaving the insulators foul the poles. This may be obviated by double arming the pole and binding each wire upon two insulators. It may also be avoided by twisting the pole, but this brings the arms out of the correct position, which is, of course, along a line bisecting the angle between the wires. In every

case the arms should be parallel with the spread of the stay.

A right angle turn in the line is provided for by arming the pole with two sets of arms at right angles to each other. In some cases the arms for the up side of the line are placed above those for the down side, but this is scarcely so satisfactory as placing the arms alternately; there is thus a difference of only six inches in the height of each wire upon either side of the pole, and the connections between the

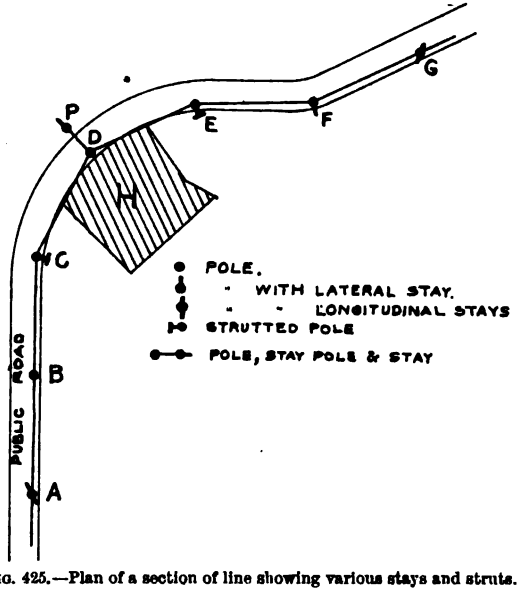


FIG. 425.—Plan of a section of line showing various stays and struts.

two sides may be made with bare wires. This arrangement weakens the pole by reason of the double set of slots which have to be cut so close together, but it is compensated for by using two V-stays at right angles to each other. The double set of arms with their connections make the pole somewhat difficult for the men to work upon, and upon this account a set of double parallel arms is preferred by some, notwithstanding the fact that it upsets the square upon telephone circuits.

A short section of line is diagrammatically shown in Fig. 425. Double longitudinal stays are shown at *A*, whilst the pole at *C* is strutted, and that at *D* is stayed across the road owing to the owner of the shaded property refusing to permit a strut to be fixed upon his land. It is, of course, also assumed that there is not space upon the road for the erection of a strut or an *A* pole. A pole is erected upon the opposite side of the road and stayed by a block and rod in the ordinary way. The resultant of the first pole is stayed to the top of the stay pole, and a tightener inserted for adjustment. It goes without saying that stays erected across roads must be given sufficient elevation to provide ample headway for heavily-laden hay wagons, etc. If stays, struts, and *A* poles are all impracticable the bend may be negotiated by increasing the number of poles round the bend; but this course is only followed in cases of absolute necessity.

The poles upon each route are numbered consecutively by means of zinc number plates nailed to the poles six feet above the ground-line in order to facilitate identification for wayleave purposes and for the issuing of instructions for renewals or repairs.

In some districts heavy winds always prevail in one direction, and where this direction is at right angles to the length of the line it is advisable to add lateral stays to provide for the extra stresses which result.

Game guards, consisting of light aluminium flags, are occasionally attached to the wires along the span in order to prevent game from flying into the wires. The small flags are hung upon the line wire to which they are attached by means of a binder in the case of copper, and iron wire in the case of iron line, wires. The small flag swings quite freely and serves to make the wires sufficiently conspicuous for the birds to avoid them.

Aërial Cables.

Aërial cables are used to carry the wires beneath bridges or in other circumstances in which it is impossible to obtain clearance for open wires. In 12-, 16-, and 28-wire cables 40 lb. tinned copper conductors, having a resistance of not more than 22·699Ω per mile, are covered with pure Para rubber, two layers of vulcanizing India rubber, and spirally lapped with india-rubber-covered cotton tape (capacity

of core not to exceed ·378 m.f. per mile). Four cores, two coloured red and two black, are laid up round a tanned jute centre so that diagonally-opposite conductors are of dissimilar colours and are bound together by a cut cotton tape prepared with ozokerit compound. The requisite number of quadruple cores (diameter ·415 inch) are laid together, wormed with tanned jute, covered with an ozokerit-coated cotton tape laid on spirally, braided with Russian hemp-yarn prepared in ozokerit compound, and the complete cable is finally coated with the same compound. Where a larger number of wires is necessary 38-wire interruption cable is employed. The conductors are of 20 lb. tinned copper, and the thickness of the insulation is correspondingly reduced. The cores are twisted in pairs and formed into a cable with a prepared waterproof tape having a lap of ¼-inch, and then braided twice with stout cotton saturated with ozokerit.

Recently, paper and air space insulated cables have been produced, and these are now sometimes employed. The wires are arranged very much as in an underground lead-covered cable ; but instead of a lead-covering a rubber tubing is formed over the wires. The ends are terminated by pothead joints, *i. e.* joints within a sleeve made solid by filling up the spaces with insulating compound (see Chapter XXII.).

Every three feet a raw hide suspender with a double hook of the form illustrated in Fig. 426 is attached to the cable. The suspending wire is usually either one or two 400 lb. copper wires terminated at each pole, and, in order to avoid longitudinal stresses upon the cable, the cable is securely lashed to each pole with ozokerite tape.

The suspending wire is first erected, and the raw hide suspenders attached to the cable. The hooks are passed over the wire and the cable drawn along by a rope. In this way the weight

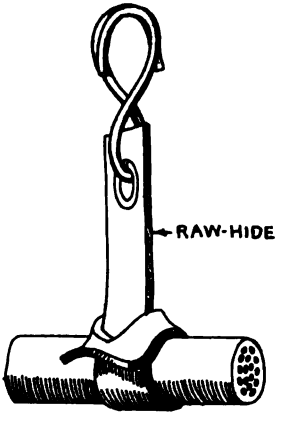


FIG. 426.—Raw hide suspender for aërial cables.

of the cable is borne by the suspending wire even whilst being erected.

The cable should be fixed as low down the pole as practicable, and chimneys must be carefully avoided owing to the action of the smoke. All risk of chafing must also be obviated. A reasonable factor of safety upon the suspending wires must be secured, and in cases where the dip has to be greatly restricted additional suspending wires may be necessary. It is, however, a simple matter to calculate the stresses with the aid of the formulæ on page 712 and a knowledge of the weight of the cable. The pole at which the open wires pass into the aërial cable usually requires a longitudinal stay to counteract the greater stress exerted by the aërial lines.

The use of aërial cables is confined to cases of absolute necessity on account of their cost and the resistance and capacity of the wires. Moreover, the life of the cable is limited, and mere inspection fails to reveal incipient defects.

OVERHOUSE CONSTRUCTION.

The term "overhouse" is employed to denote all those cases in which the wires are carried upon supports fixed to buildings, or in which timber of exceptional length is necessary, but the object of the present section is to deal only with the former cases.

The line wire is invariably either copper or bronze of a light character in order to reduce the stress to the lowest possible limit. If solid wires are used, 70 lb. bronze, 100 lb. copper or even 150 lb. copper may be chosen, but, when trouble arises from the humming of the wires, either $\frac{3}{18}$ or, where it is imperative to keep down the resistance of the circuit, $\frac{7}{18}$ stranded copper (see table on page 674) wire is employed. The wires are terminated at very frequent intervals, thus securing greater immunity from breakages, and eliminating the possibility of a broken wire running back through an imperfectly attached binder. Upon each side of every street crossed by the route the wires are invariably terminated and the length of the span is kept as short as possible. When wiring operations are in progress men are stationed in positions where they can readily stop

the traffic in the event of a wire being in such a position as to cause danger, but in most cases the wires are pulled across with the aid of an endless sashline, thus obviating an interference with the traffic below. The only other point calling for particular mention is the danger attaching to the use of a fire pot upon a roof: it should be placed upon stone or brickwork, kept well clear of any lead work, and a man should always be left in charge of it.

Humming of Wires. Silencing Devices.

The well-known humming noise which is produced by telegraph wires under certain atmospheric conditions is usually of little or no consequence in the case of road lines, but when the wires are carried by supports fixed to buildings, the sound is transmitted by the walls and partitions to the interior. In some cases, no doubt, resonance also tends to increase the noise to such an extent as to cause most serious annoyance. The effect is greatest when the wires are erected in long spans and are tightly stretched, but it is noticeable that the volume of the noise is not in direct proportion to the velocity of the wind, since it is frequently greatest upon a comparatively calm day. Many silencing devices (variously termed *sourdines*, deafeners, and silencers) of a more or less effective character have been devised.

When the wires terminate upon a support fixed to a building, as for example upon a bracket, the noise can be very greatly reduced by terminating and slackening out the wires in the last span. In addition, the line wire may be covered with india-rubber by placing a length of tubing over the wire where it passes around the insulator; or again a strip of wood about two feet long bound round each wire close to the insulator will sometimes prove quite effectual.

In the case of roof standards (see Fig. 430) it will be observed that there is a packing of lead and felt between the chair and the ridge of the roof which tends to insulate the vibrations.

Sourdine Caël Beau. Yarn to a thickness equal to the diameter of the wire is tightly wrapped round the line wire for a distance of about 12 inches. Over this is placed a split rubber tube of such a diameter as to completely enclose the yarn, and finally a wrapping of lead is placed over the rubber tube. The binding wire where it encircles the

insulator is treated in a precisely similar manner and the ends are made off upon the leaden covering of the line wire.

National Telephone Company's standard arrangement. A narrow strip of thin lead is wrapped around the wire for

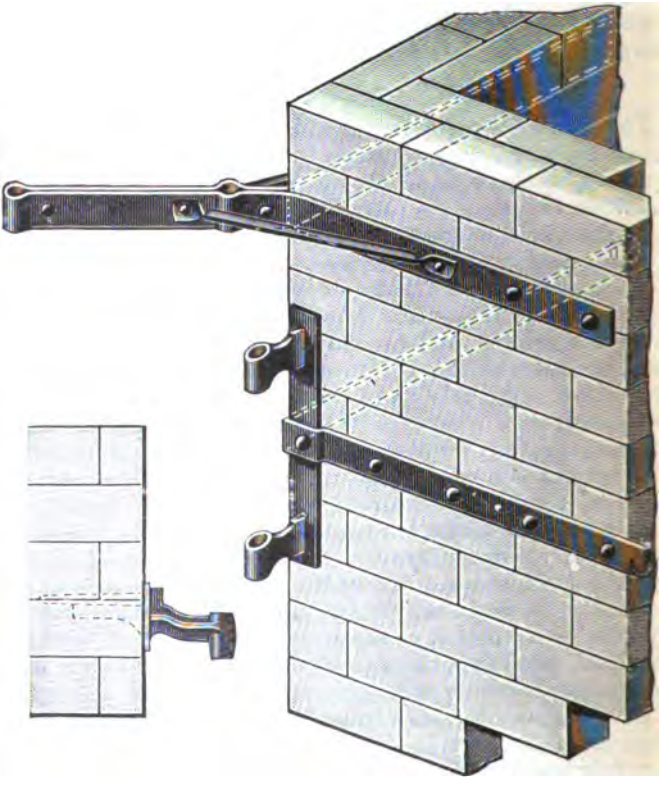


FIG. 427.—Double horizontal and vertical brackets and single bracket. (Note.—The arrangement of the brickwork is incorrectly shown, since there is no bond.)

a distance of eight inches upon each side of the insulator, the central portion taking one turn around the insulator. Its efficiency may, however, be increased by placing yarn between the wire and leaden wrapping.

Chain silencer. A short length of chain is inserted in the line wire and the ends bridged across by a length of conductor so as to preserve the electrical continuity of the circuit.

For brackets. A rubber washer placed between the flange of the insulator spindle and the top of the bracket, and one between the nut and the bottom of the bracket, is most effective and greatly diminishes the noise.

In conclusion of this subject, it should be stated that light stranded copper wire produces far less noise than a solid wire under similar conditions.

Brackets.

Angle brackets, fixed upon the corners of walls and chimneys, are frequently employed when the route is to carry a maximum of six wires. The brackets should only be attached to sound buildings, and a wall is to be preferred to a chimney, but where the latter is the only available position the brackets should be kept as low as possible. It is also very desirable to arrange matters so that the stress upon the bracket, due to an angle in the line, tends to push the bracket on to, and not pull it away from, the chimney. In the former case the only function of the nails is to support the bracket, whilst in the latter they have to resist a definite stress, and the brickwork will therefore require to be plugged—frequently a hazardous proceeding, since most chimneys are only $4\frac{1}{2}$″ brickwork.

The double vertical bracket (Fig. 427) is especially suitable for use upon chimney stacks owing to the provision of the two eyes, by means of which a $\frac{7}{16}$ stranded iron stay wire may be passed around the stack. At each of the three corners an angle plate 9″ deep carrying a projecting eye is fixed, so as to prevent the stay wire from cutting into the brickwork. This arrangement obviates the necessity for using so many nails, and so saves the chimney from any unnecessary damage and the occupants of the house from a certain amount of annoyance, due to falling soot and noise, which occurs whilst the bracket is being fixed.

The horizontal bracket (Fig. 427) is used only upon the corners of buildings of substantial character owing to the fact that the leverage of the outer wire is very considerable.

STANDARDS.

The safety of a building would be imperilled if its roof timbers were utilized for the same purpose as the five or six feet of earth in which a ground pole is embedded, viz. to hold the base of the pole rigid when the upper portions are subjected to lateral stresses due to wind pressure. In the event of the collapse of the wires upon one side of the standard, such as might for example be caused by a fire at an adjacent building, a very heavy strain in a direction at right angles to that produced by wind pressure across the wires would result. It is therefore necessary to so arrange the structure that the only stress upon the roof shall be in a downward direction, and this is readily accomplished by the employment of four or more stays. Motion of the pole is resisted by tensile stresses upon the stays and by downward or crushing stress upon the pole. Every roof pole is stayed in four directions, and it is preferable to arrange the stays so that the line of the wires bisects the opposite angles formed by the plan of the four stays. In this way either a laterally or a longitudinally applied stress is divided between two stays (see Fig. 430.)

The average roof is not constructed with a view to the erection of a standard upon it, and the conditions to be met in each case vary so much that it is only possible to describe two or three typical cases, and from them illustrate the general underlying features of satisfactory design. The stresses should be transmitted to the outer or main walls in such a manner that the standard becomes an integral part of the building to which it is attached. It should be ascertained that the roof timber is of such dimensions as to safely take the extra stress thrown upon it, should the whole of the wires collapse upon either side of the pole; and where this is not the case an additional beam of timber or a suitable steel joist connecting the main walls should be added. The stays should be anchored low enough down the main wall: the stress, if considerable, being distributed by using wall plates, to ensure that the brickwork shall not be displaced by any stresses to which the stays can conceivably be subjected. The *lateral* stresses upon the walls must be reduced to the lowest possible limits, whilst an upward pull upon the rafters of the roof is especially to be avoided. It is particularly inadvisable to bolt a pole to an end wall

when thoroughly efficient staying facilities are not available.

Buildings which have been specially constructed for the reception of large standards are so arranged that, in some cases, the poles pass right down to the foundations and are braced together and stayed to the walls in such a manner that nothing short of a collapse of the whole building could affect their security.

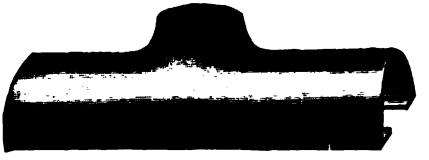


FIG. 428.—Chair for roof poles.

Square pitch pine poles passing through the roof of the building were at one time somewhat extensively employed, but since the pole is subject to vibration there is some difficulty in maintaining a perfectly watertight joint at the point where the pole passes through the roof. The difficulty is by no means insuperable, and this method of

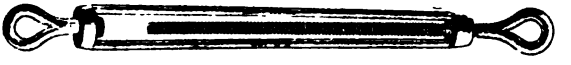


FIG. 429.—Swivel for stays upon overhouse fixtures.

construction has much to commend it, since the pole may be supported upon or carried by the tie beam of the roof.

The present practice is to use iron poles carried by a cast-iron chair (Fig. 428) placed upon the ridge of the roof as shown in Fig. 430. The pole itself is dipped whilst hot into boiled linseed oil, since it is found that this treatment is more effective than galvanizing. Felt and lead are placed beneath the chair in order to prevent the vibrations, due to the humming of the wires, from being transmitted through the roof timbers to the interior of the building. Climbing clips, which correspond to the pole steps used upon ground poles, are fitted at regular intervals and at the upper part of the tube a collar for the attachment of the

stays is shrunk on. The tubular iron arms are of the same pattern as those used with iron ground poles (see Fig. 413)

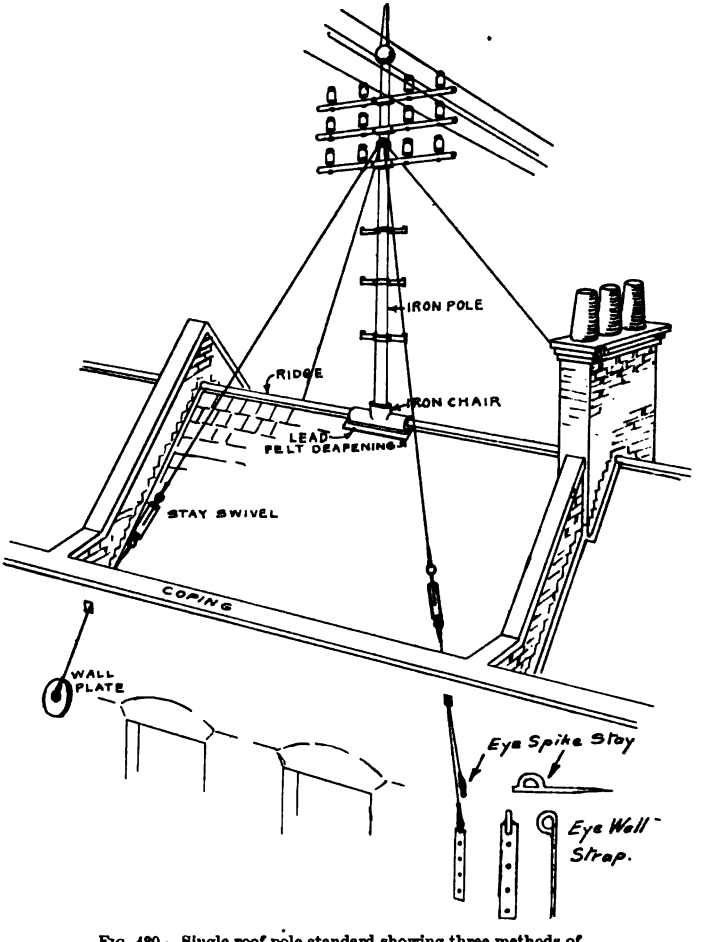


Fig. 480.—Single roof-pole standard showing three methods of anchoring the stays.

and are furnished with wooden insulating strips as previously described.

The stays should, where possible, be anchored to the main

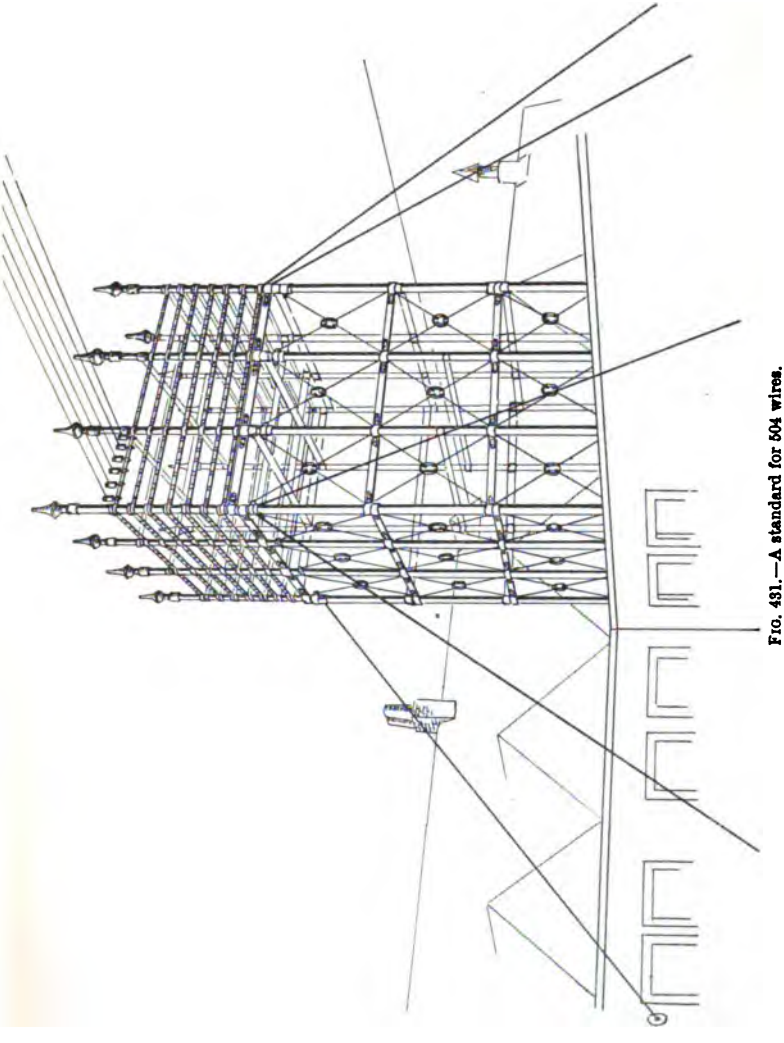


FIG. 431.—A standard for 504 wires.

walls of the building sufficiently low down for security.

Where the beams of the roof are employed, collars should be fitted, and under no circumstances should bolt holes be cut. Care must also be taken not to put a stress upon a coping which tends to displace it. In the majority of cases, a hole is provided for the stay as shown in Fig. 430, but by fixing a block of wood of triangular section with its base uppermost at the bottom of the coping wall, it is sometimes possible to obtain a satisfactory clearance.

Three methods of anchoring the stays, each of which is fitted with a swivel (Fig. 429), are shown in Fig. 430, firstly by means of an eye spike driven into the brickwork, secondly by means of a G.I. strap nailed to the wall, and thirdly with the aid of wall plates. The last method consists in placing a plate upon each side of the wall and bolting them together, thus ensuring a thoroughly efficient hold upon the brickwork. In the case of very heavy stresses the size of the plates may be increased, and the two sides bolted together independently of the eye bolt to which the stay is attached, the effect being to thus distribute the stress over a larger area. The use of wall straps, owing to their inefficiency, is avoided wherever it is possible.

Where the standard is to be fixed upon a girder or upon the end of a wall, a chair of rectangular section to fit over the wall or girder is substituted for the semicircular chair shown in Fig. 428.

A double or two-pole standard is carried by a rolled steel joist upon which the two cast-iron chairs are placed and the poles are braced together in a manner very similar to that employed for H-poles, whilst the channel iron arms serve to secure the upper portions of the poles. These arms are made in two pieces and are bolted together upon each side of each insulator spindle and each pole hole.

An example of a large standard recently designed by M. F. Roberts is illustrated in Fig. 431. In the centre of the large well of the building a heavy brick tower was built and the standard placed upon it. It will be observed that the general construction bears some resemblance to the H-poles previously described and that the various poles are also braced across in such a manner as to secure remarkable strength and rigidity. The channel iron arms serve to brace the heads of the poles and the structure is capable of carrying 504 wires.

CHAPTER XXII

THE CONSTRUCTION OF UNDERGROUND LINES.

IT is frequently quite impossible to erect open wires in the centre and more congested parts of large towns and cities, and, in such cases, there is, of course, no alternative to the provision of underground routes. There are, also, many cases in which the number of wires needed exceeds the capacity of an aërial line.

The objection to underground circuits is chiefly upon the score of cost. It has been shown that the working speed of an underground wire is considerably less than that of an aërial circuit, but, by increasing the diameter of the copper conductor and the thickness of the gutta-percha covering, the working speed may be increased to any required value. This increases the cost of the wire itself and also the cost of the conduit, since a much smaller number of the larger wires can be accommodated within a conduit of given size. The same principle applies to air space and paper core cables, and therefore it may be said that the objection to underground routes is solely on account of the expense. The electrical disadvantage (the reduction of the working speed) attendant upon the use of underground circuits, presents not the slightest difficulty when the question of cost is ignored.

The greatest advantage derived from the use of underground, as opposed to aërial, lines lies in the greater immunity from interruptions. An aërial line may be broken down by the force of a gale, the wires may be broken by the weight of snow and ice which they have to bear, insulators may be fractured by stone throwing, or the insulation may be impaired by wet weather. From each

of these sources of trouble the underground line is free, whilst the only likely causes of trouble lie in (1) the damage which may he done during road repair, (2) contacts with electric light feeders, and (3) a general sinking of the ground in which the pipes or ducts are laid. The number of cases in which any of these difficulties appear is well-nigh insignificant.

It is often pointed out that underground wires are less accessible than open ones, and that the difficulty of dealing with faults is enormously increased. Since the number of faults which occur is extremely small and fairly accurate localization tests can usually be made there is little justification for objection upon this score.

The provision of main routes of underground connecting the larger towns and cities ensures that the telegraph work of the country shall not be stopped or disorganized by the prevalence of storms. Incidentally, it may be remarked that one of the most fruitful causes of such breakdowns is that trees are uprooted and bodily blown over on to the lines.

CONDUITS.

Many forms of conduit have been proposed, but iron pipes and earthenware ducts are the only forms used by the Post Office. One administration has gone so far as to dispense with the conduit altogether and to lay their telephone cable directly in the earth. The cable is, of course, protected by suitable armouring, and, upon the score of economy in first cost, there is perhaps something to be said for such a system. Its disadvantage is that the changing or renewal of a cable entails opening the streets—a very costly proceeding.

Iron Pipes.

The pipes are cast from soft pig-iron of good quality, and, after being thoroughly cleaned to remove all sand, grit, or metallic excrescences, are heated, and then dipped into Dr. Angus Smith's composition, which consists of :—

Coal tar . . .	1 cwt.
Tallow	7 lbs.
Quicklime, slaked .	10 ,,
Pine, resin . . .	4 ,,
Coal naphtha . .	sufficient to thin the composition to a degree suitable for proper coating.

This composition produces a hard glaze upon the surfaces of the pipes, which tends to protect them against rusting.

The specification for each size of pipe states the minimum internal diameter and also the minimum weight of the pipe, which fixes the thickness of the metal. The pipes are tested with a circular gauging disc having a diameter one-sixteenth of an inch less than the internal

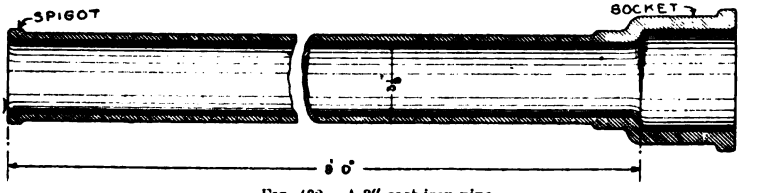


FIG. 432.—A 3″ cast-iron pipe.

diameter of the pipes. The other important points to be observed are that the pipes shall be smooth, and the thickness of the metal quite uniform.

The four sizes of pipe used by the Post Office are distinguished by quoting the internal diameters. The 2″ pipes are made in lengths which give a "lay" of 6 feet, whilst the 3″, 3¼″ and 4″ pipes have a lay of 9 feet per pipe—for example, 150 2″-pipes or 100 3″-pipes are required to provide 300 yards of conduit.

A 3″-pipe is illustrated in Fig. 432, from which it will be observed that the spigot end is rounded off so as to fit into the socket of the subsequent pipe. In order to joint the pipes the spigot end is placed within the following pipe, after which a suitable quantity (about two inches deep) of spun yarn is lightly wrapped round the pipe, and driven home with a caulking iron. In order to fill the annular space between the spigot and socket ends of the pipes with

lead, a roll of plastic clay is laid around the edge of the socket so as to leave an opening at the top. Through this, molten lead is poured, and, after cooling for about one minute, the clay is removed. The lead is well punned with the aid of a lead set of suitable dimensions, so producing an air and water tight joint of considerable strength (Fig. 433). If the yarn is omitted, the molten lead runs into the pipe, which it effectually blocks, but this should be discovered when testing the pipes during laying.

Usually the pipes are jointed in pairs at the side of the trench, and, for this purpose, they are laid upon wooden pipe blocks which raise them about six inches from the

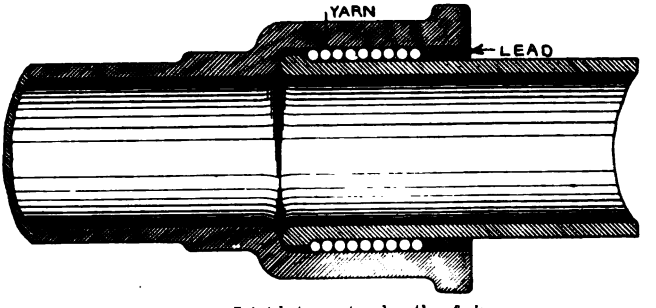


FIG. 433.—Joint between two lengths of pipe.

ground. When more than two pipes are jointed before being placed in position in the trench, there is some risk of the joints being opened by the stresses put upon them whilst carrying them. As each length is laid, the mouth of the pipe is closed by a wooden plug in order to prevent the ingress of stones and dirt from the trench.

The pipes are laid directly in the ground without any concrete or other foundation, since the nature of their design gives them very great strength. In fact, the only way in which they can fail is by the joint drawing, but the number of cases in which this occurs is quite insignificant.

Where two or more pipes are laid in a single trench the pipe joints should be so spaced that they do not occur at the same points along the route, since this is economical in the space occupied and also tends towards greater rigidity.

As each length of pipe is laid a " draw wire " consisting

of either 200 lb. or 400 lb. iron wire is threaded through the pipes. This wire serves to pull the cable rope through the pipes and obviates the labour involved in using sweeps' rods (*q.v.*).

Each pipe entering a jointing chamber terminates with a bell-shaped mouth. Such a pipe is illustrated in Fig. 434, but as the pipe may require to join the socket end of

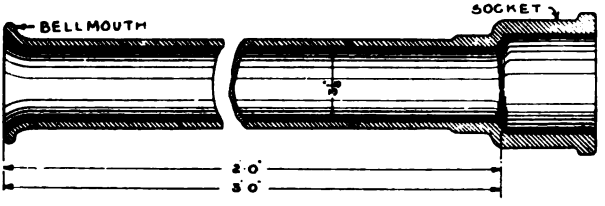


FIG. 434.—A bell-mouthed pipe.

the main pipe it will be obvious that bell-mouthed pipes having spigot ends are also needed. It is, however, more usual to cut the pipes so that the spigot ends enter the box, thus obviating the necessity for bell-mouthed pipes (see page 753).

Slight curves in the route may be negotiated by giving the pipes a slight set at the joints, but whenever the curve is of a pronounced character curved pipes or bends (Fig. 435) are used. A number of bends of varying lengths and curva-

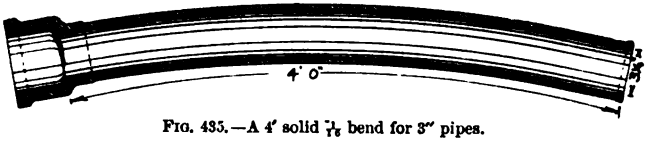


FIG. 435.—A 4' solid $\frac{1}{16}$ bend for 3" pipes.

ture, some provided with sockets at both ends and some with spigot and socket ends, have been designed to meet these cases. The $\frac{1}{16}$ bends with a lay of 6 feet are probably used more often than any of the others, although the $\frac{1}{8}$ and $\frac{1}{32}$ bends are also extensively employed. The terms $\frac{1}{8}$, $\frac{1}{4}$, $\frac{1}{16}$, $\frac{1}{32}$ denote the fraction of the total circumference of the circle which the bends represent. For instance, the $\frac{1}{16}$ 6 feet bend has the curvature of $\frac{1}{16}$ of a circle 14 feet in radius.

The cost of constructing a line of conduits varies very considerably with the character of the roadway or footway which is disturbed. The cost per yard run of a 3 inch pipe laid beneath a gravel footway might be as low as 3*s.* 6*d.*, whilst beneath a wood block carriage-way it might be in excess of 16*s.* The difference is almost entirely due to the cost of reinstating the footway between the edges of the trench line.

The following figures* show the average prices charged by the various Metropolitan local authorities for the reinstatement of trenches :—

† York stone	1*s.* 8·64*d.* per sq. yd.
Tar paving	4*s.* 0·76*d.* ,,
Asphalte footway	8*s.* 6·31*d.* ,,
Asphalte carriage-way	14*s.* 3*d.* ,,
Pitched ,, relaid on Concrete,	4*s.* 10·66*d.* ,,
Macadam	2*s.* 2·3*d.* ,,
Ballast or flints	1*s.* 6·35*d.* ,,
Wood relaid	15*s.* 11·4*d.* ,,
† Brick	3*s.* 5·75*d.* ,,

Beneath footways the pipes are laid at a minimum depth of 12 inches, but under roadways a minimum depth of 2 feet is essential.

Duct Routes.

Where more than five conduits are needed along the same route, it is more economical to use earthenware ducts in place of iron pipes, and the larger the number required the greater is the saving effected. The duct used by the Post Office is 18 inches long with a $3\frac{1}{4}$ inch circular bore and an octagonal exterior (Fig. 436). The ducts are laid upon a strengthened concrete foundation and are jointed with ozokerit tape (4 inches wide) laid around the joint. Two inches of the tape upon each side of the joint adhere to the successive ducts, but it is really to the rigidity of the foundation that the joint owes its perfection.

A train of mandrels is placed in each duct line and is

* Extracted from a return prepared by the Lambeth (London) Council, *Electrician*, 5th August, 1904, page 653.

† In these two cases must be added the cost of replacing all broken or damaged stones or bricks.

pulled forward as each joint is made (Fig. 437). This ensures perfect alignment by preventing any length of duct from sinking or falling after being laid. When the manhole is reached a mandrel 5 feet long is employed to preclude the possibility of disturbance to the nearer joints whilst the chamber is being constructed. Finally, the ducts

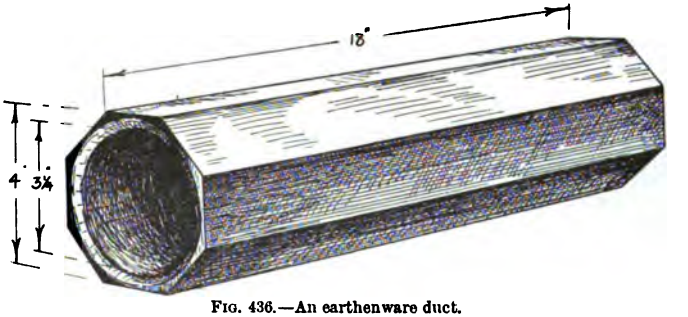


FIG. 436.—An earthenware duct.

are tested by drawing a mandrel through the whole section and are cleaned out by the circular brush which follows it.

A trench of suitable dimensions is formed and a 3 inch layer of concrete laid down (Fig. 438). Upon this, one, two, or more T-irons, jointed up by fishplates, are placed and covered by a second 3 inch layer of concrete. This foundation is allowed to dry for 24 hours, after which a thin layer of cement mortar or "compo" is formed, and

FIG. 437.—Train of mandrels in the ducts during the process of laying.

the first or lowest row of ducts bedded upon it. More "compo" is added and the subsequent tier of ducts laid down, and so on, until the complete nest of conduits has been built up. If the roadway is of macadam or other light type of paving, the sides and top are lined by a 6 inch solid concrete wall, whilst under wood block or asphalte roads 4 inches of concrete is ample, since the paving itself is laid upon a heavy concrete bed.

Consideration will show that this form of construction results in a compact block of conduits (Fig. 439) of considerable rigidity, the T-iron serving to prevent any possibility of vertical displacement. The joints between the successive ducts are not made at the same points along the route, but are "broken" as indicated in Fig. 438.

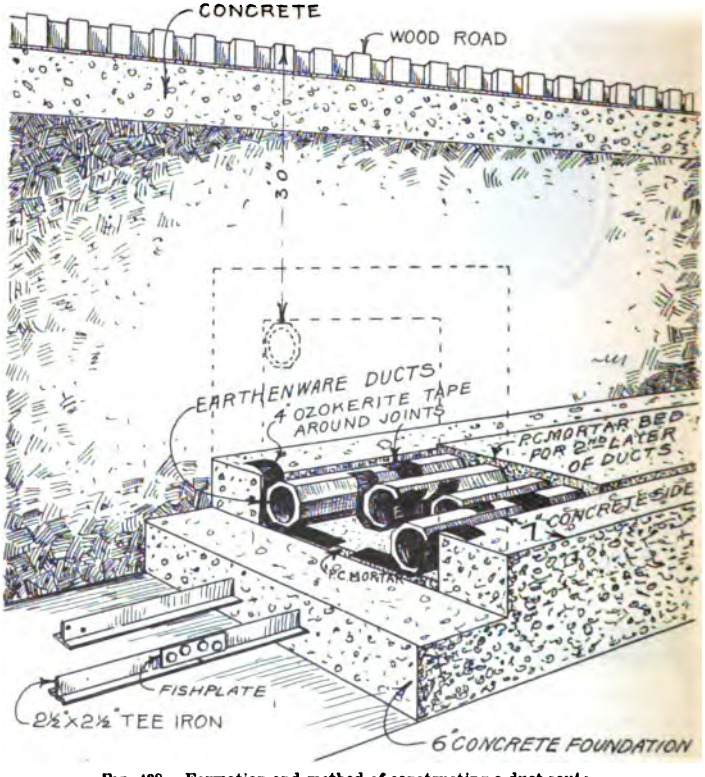


FIG. 438.—Formation and method of constructing a duct route.

It will be realized that ducts do not lend themselves to the negotiation of curves, and in such cases iron pipes are used in the curvilinear section, since the joint between iron pipes and a nest of ducts presents no difficulty whatever. The single duct used by the Post Office possesses the

advantage that the arrangement of the group may be varied to clear obstacles *en route*, whereas a multiple way duct does not give this facility and it is, no doubt, largely due to this fact that the single duct was adopted.

Slide Pipes.

Two methods of providing for the joints between successive lengths of air space cable have been used. The first consists in leaving a suitable gap in the pipe line at each point where a joint is required, and to cover the com-

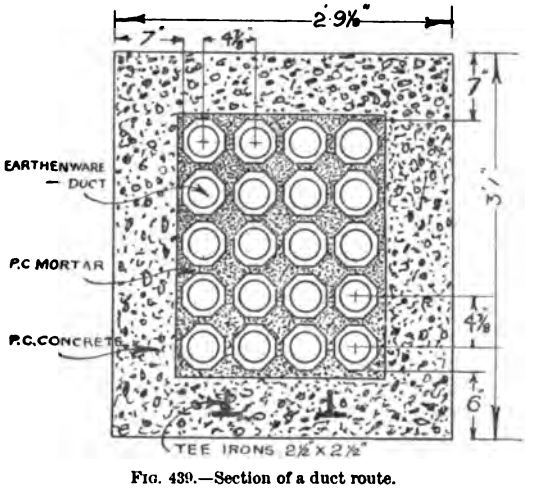


Fig. 439.—Section of a duct route.

pleted joint by means of a slide pipe. Before the joint between the two lengths of cable is made a pipe 4 feet 8 inches long and 4 inches in internal diameter is slipped over one end of the 3 inch pipe and pushed back out of the way of the cable. The cable joint is then made and tested and the slide pipe pulled over so that its ends overlap the ends of the pipes upon either side. Yarn is then worked in between the ends of the slide pipe and the ends of the pipe line and the joint leaded in the ordinary way, thus securing an air and water tight joint.

Whenever it is necessary to obtain access to the joints, the ground is opened and the lead picked out from the

joints with the aid of a special tool which somewhat resembles a diamond-pointed chisel. When it is necessary for any purpose to cut the pipes, the gap thus made is filled by using a length of split pipe, *i. e.* a pipe made in two halves which are secured together by four pairs of cotters and pins.

The positions at which joints have been made are, of course, carefully recorded, but, in addition, cast-iron "markers" are placed above the joints flush with the paving, or, where no pavement exists, a sign stating the horizontal distance from the sign to the joint is placed at the side of the road. As it may be many years before it is necessary to disturb the ground there is less disadvantage in this procedure than would, at first sight, be imagined. The first cost of the system is, of course, far less than that in which jointing chambers are employed.

In those cases in which the lead cable joint is provided with an air cap the slide pipe cannot be used, and in order to meet this requirement a new form of coupling, consisting of a longitudinally split pipe provided with flanges for securing the two sections together and having the upper half so shaped as to provided ample accommodation, has recently been introduced.

The present practice is to confine the use of slide pipes or couplings to those cases in which but one, or even two pipes, have to be laid beneath the roadway, as for example in the case of a country road in which there is no defined footway upon either side, the construction of roadway manholes being exceedingly costly whilst the ordinary forms of joint box and their covers are not designed to withstand the stresses produced by heavy wheeled traffic.

It should be stated that the use of slide pipes entails the making of a hole of fairly large dimensions for the pulling in and subsequent jointing of the cable.

Pillar Test Boxes.

The slide pipe system has only been used in the case of long main routes, and at intervals of every 3 or 4 miles pillar test boxes are inserted to provide crossing and testing facilities should the occasion arise. These boxes somewhat resemble the section boxes used for electric tramway routes

and rest upon 12 inches of brickwork built upon about 6 inches of concrete. About 10 inches of the cast-iron frame of the pillar, which is five feet in height, is below the ground line. The upper portion of the box contains space and fittings for the reception of a cable connection box (*q.v.*) of suitable form.

Flush Boxes and Pit Channels.

The varying requirements are met by using six standard sizes of joint box having the dimensions shown in the table below :—

Type.	Length.	Breadth.
Distribution	1′ 3″	9″
Small	2′ 5″	10″
Large	3′	15″
Extra Large	3′	18″
Single Junction. . .	2′	2′
Double Junction . .	4′ 4″	2′

The distribution box is used solely in conjunction with the London telephone system at a point to which the house connections are brought, and joints in the 7-pair cables are never made in them. The small box is sometimes used upon minor telegraph routes where gutta-percha cable is drawn through without joints, and it is also employed as a joint box for a small number of wires. The type of box chosen, of course, depends entirely upon the number of pipes, the angles at which they enter and leave the box, and upon the space required by the joint or joints.

The special purpose of the single junction box is to provide for a lateral pipe at the corner of a street. It is also used where there are right-angle turns in the route. The double-junction box provides for large numbers of wires or large cable joints, and may be used where the main route consists of two pipes.

The extra large type is adequate for two pipes provided that there is sufficient room for jointing the cables, and as will have been noticed, it is of the same length as, but of greater width than, the "large" box.

In order to reduce the size of the boxes needed for making

joints in large cables "terminating pipes" are frequently employed. A "3 to 4 inch terminating pipe" consists of a pipe 4 inches in diameter, but narrowing down at the point where it is jointed to the socket of the ordinary 3" pipe. In this way the lead jointing sleeve may be pushed up the terminating pipe and thus reduce the length of the jointing chamber to that actually occupied by the joint itself, but allowing, in addition, suitable room for working.

The construction of the various types of box differ in little save their dimensions, and a detailed description of a "large" box will probably suffice to render the general arrangements of the various types quite apparent.

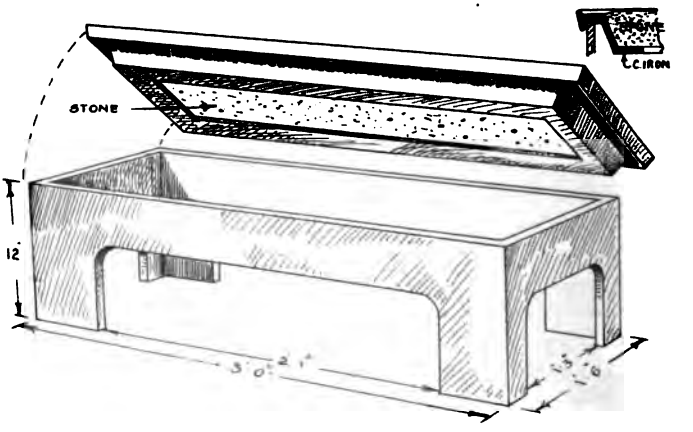


FIG. 440.—An extra large joint box.

The cast-iron body of a large box, together with its more important dimensions, are shown in Fig. 440. The lid (Fig. 441) consists of an iron casting, so shaped as to receive and support the slab of asphalte (3" in thickness) which is cemented to it. Since the lip of the cover projects over the edges of the box body, it is frequently necessary to protect the lip by placing an edging of stone 2" wide and $4\frac{1}{2}$" deep right round the box (see Fig. 442). Where the paving is of York or artificial stone the edging may, of course, be omitted.

When the line of pipes is being laid the requisite gaps are left at each box, but care is taken that the ends of the

pipes shall terminate at the spigot ends, which is readily effected either by cutting the last pipe to the requisite length and making the joint with the *cut* end or by shortening the last pipe but one.

A hole of suitable dimensions is prepared and the bottom lined with 3″ of concrete upon which one, two, or more courses of bricks are built according to the requirements of the case. Upon the top of this the box body is placed and bricked up in the manner indicated in Fig. 442, the pipe entering the box within the hollowed end of the body. Where the pipe enters at a lower level it is customary to

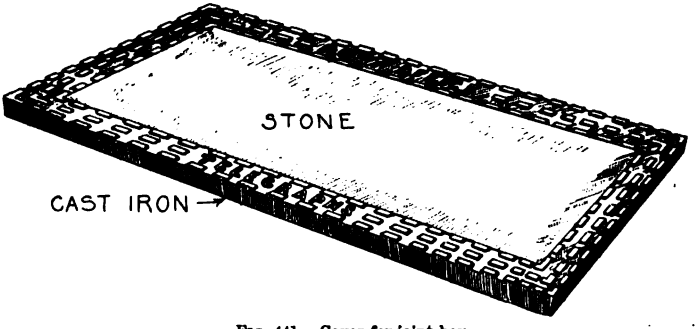


FIG. 441.—Cover for joint box.

increase the depth of the box so that there are two courses of brickwork below the lower pipe.

The double junction box is provided with two lids, each 2 feet square of the same type as that used on single junction boxes. The centre of the box, where the two lids meet, is provided with a removable cross-piece upon which the lids normally rest. Apart from this, there is nothing which calls for comment in the five types of box not discussed in detail.

In addition to the boxes described "pit channels" are made in the same six sizes and differ from the boxes in the absence of the "legs." A pit channel occupies less space for storage, but it requires more bricks in building, whilst the frame is cheaper than a box body on account of the smaller weight of iron. In every case the lips of the lids fit within the edges of the frame, and stone edging is,

therefore, unnecessary. The pit channel forms the only type of jointing chamber which can be used where sufficient depth cannot be obtained for a box. In such cases the pipe may be brought much nearer to the surface, and a fairly satisfactory space provided. At the same time it must be admitted that pit channels permit much more water to enter the box than is the case with joint boxes owing to

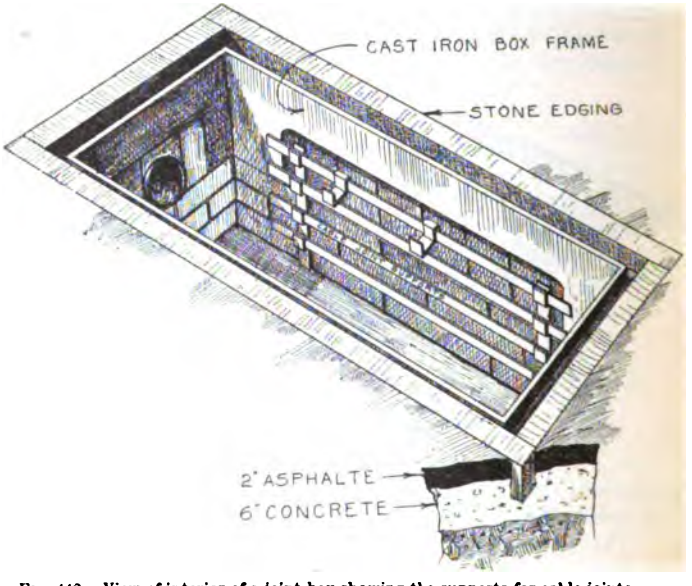


FIG. 442.—View of interior of a joint box showing the supports for cable joints.

the fact that the lids of the latter fit *over* the edges of the body of the box.

MANHOLES.

Where there are several pipes, or at important junction points between main routes, manholes are constructed. They may be formed beneath the footway or the roadway, and for small sizes the former is preferable, since the lesser strength requisite can be obtained without undue expense. The manholes beneath the roadway must be capable of

supporting the heaviest traffic, and are therefore of a heavier type. Usually the footways are largely taken up by gas, water, electric light, tramway, and other services, and the space for the construction of a large manhole is not available.

The smallest type of footway manhole is built with 9″ brick walls upon a 6″ concrete foundation "rendered" with $\frac{3}{4}$″ of cement. A double junction pit channel covers half of

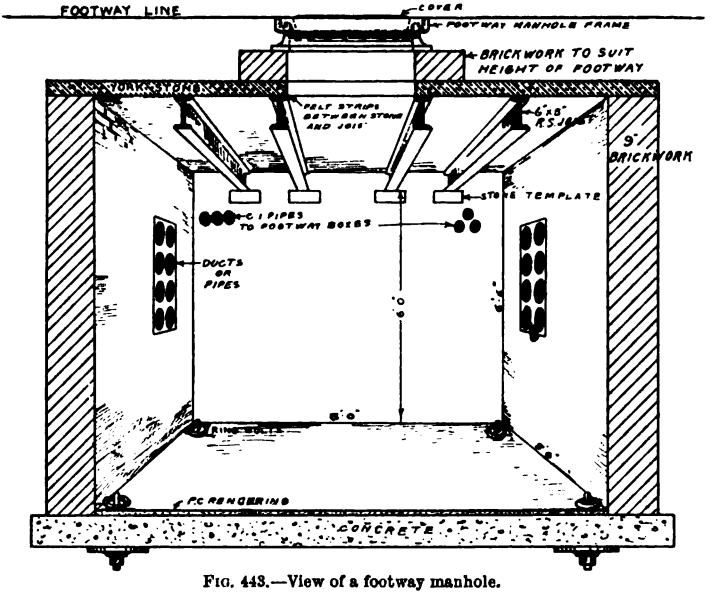


FIG. 443.—View of a footway manhole.

the top, whilst a boiler plate $\frac{1}{2}$″ in thickness, supported by the brickwork upon three sides and by a rolled steel tee upon the fourth, covers the half immediately above the pipes. Upon this plate a suitable layer of concrete serves to support a York stone, the face of which is flush with the lids of the pit channel.

A larger type of footway manhole is illustrated in Fig. 443 from which it will be seen that the roof is formed by York stones carried upon 6″ × 5″ rolled steel joists supported at each end upon stone templates built into the brickwork

of the sides. The entrance is formed by adding a footway manhole frame or cover, the design of which closely resembles the single junction pit channel previously described.

At each corner of the manhole ringbolts are fixed to facilitate the operation of pulling the cable into the pipes.

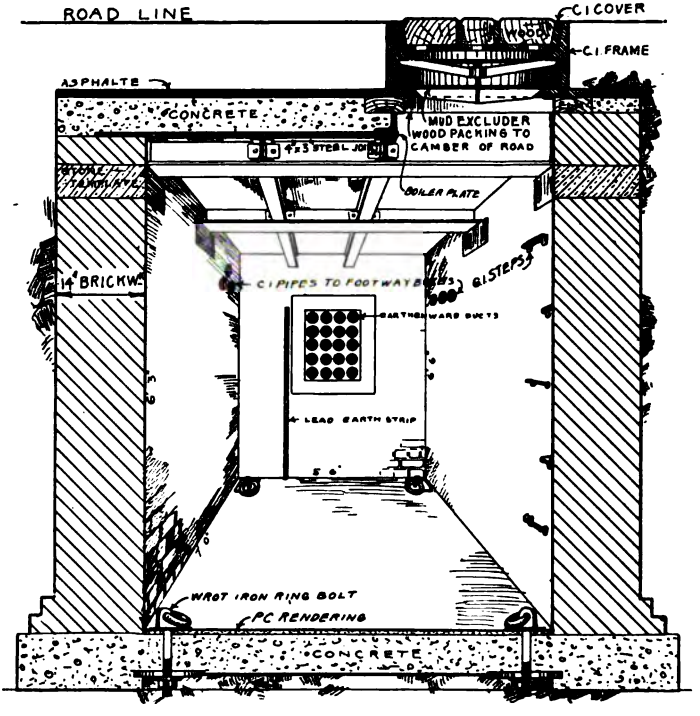


FIG. 444.—A roadway manhole.

Galvanized iron steps are fixed into one of the end walls, as indicated in the figures. Iron cable supports 2″ wide, slightly hollowed, are provided to carry the cables across the manhole. The entrance is invariably at the side of the manhole so that there shall be no danger of the cables being damaged by workmen stepping upon them as might readily happen were the entrance placed directly over the cables.

When earthenware ducts are used the lead sheathings of the whole of the cables are joined with lead strip to the leaden earth plate, which is placed below the concrete foundation. The object of the arrangement is to prevent electrolytic damage to the cable sheathings produced by stray or return currents from electric tramway systems.

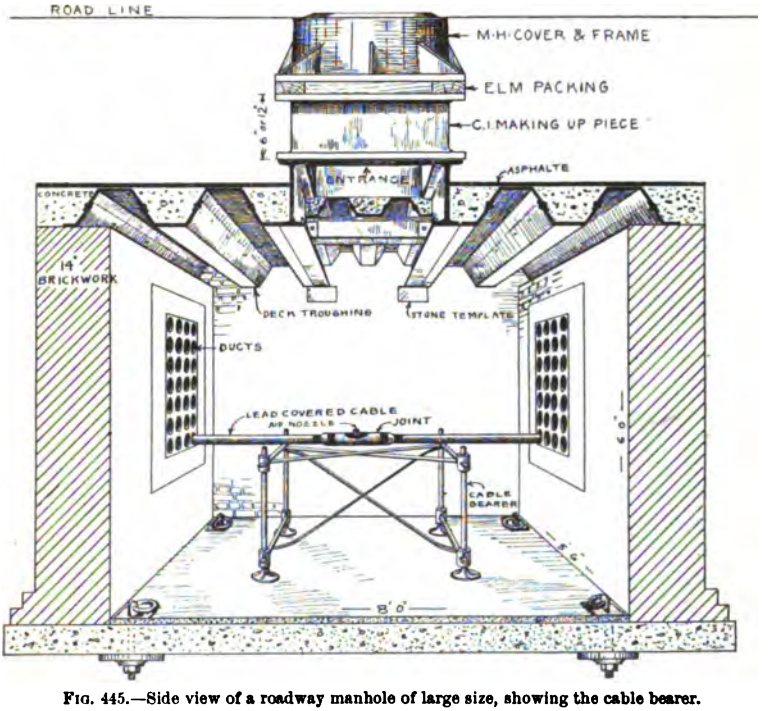


FIG. 445.—Side view of a roadway manhole of large size, showing the cable bearer.

Roadway manholes are built in somewhat similar fashion, but the entrance is closed first by means of an iron plate, clamped down on to an india-rubber ring resting upon a flange, which prevents any mud which may work its way between the cover and the frame from entering the interior of the manhole, and then by the cover, which consists of an iron casting fitted with wood blocks in the type of which an

end view is given in Fig. 444, the mud excluder is of a slightly different pattern, a spider and screw replacing the four clamping handles of the older type. It will also be observed that the brickwork of the retaining walls is 14″ thick as against 9″ of the footway manhole, and that the roof is formed by a series of steel joists carrying boiler plate, concrete, and finally a layer of asphalte upon which the road is constructed.

A manhole of larger and heavier type is depicted in Fig. 445, and differs from the one previously described in the use of deck troughing, and also in the slightly different arrangement of the entrance. It may, however, be remarked that in later types the cast-iron making up piece is substituted by brickwork of similar formation.

The cables are supported upon a cable-bearer placed against the side wall more remote from the opening. It consists of four tubular supports braced together, and to which additional tiers may be added as the number of cables increases. Each tier supports the whole of the cables entering the manhole at the same level.

The whole of the various types of manhole, together with the various special arrangements indicated, were designed by M. F. Roberts, for use in connection with the Post Office London Telephone system.

In flush-boxes supports fixed into the brickwork at the side of the box are frequently used to support double solid or other types of joint (see Fig. 442).

Gutta-percha-covered Wires.

The type of wire formerly used for underground circuits is known as "No. $7\frac{1}{2}$ G.P. prepared," the "$7\frac{1}{2}$" relating to the total gauge of the completed wire. The copper conductor is 50 mils in diameter, weighing 40 lbs. per mile, whilst the covering has a major diameter of 174 mils and weighs 50 lbs. to the mile. Single wires are spirally wrapped with ozokerit tape as a mechanical protection to the insulator, whilst quadruple cables are formed by spirally wrapping four untaped wires with a broad ozokerit tape. Where thirty wires are needed seven quadruple cables and two single wires are tied together at intervals of about 3 feet, but these ties are removed as the cable is drawn into the pipes.

The minimum insulation of a new wire is 200 megohms per mile at 75° F., but rises to about 1338 megohms at the temperature of the pipes, usually about 50° F. In practice, the specified minimum value is very greatly exceeded, and is frequently from ten to twenty times as much. When the insulation falls below one megohm per mile the wire is considered faulty, and is renewed forthwith.

The disadvantages of gutta-percha wires when laid underground consist in the cost, electrical inefficiency, and the deterioration which more or less rapidly sets in. The life of a gutta-percha-covered wire is greatest when it is continuously under water, as in the case of submarine cables. When exposed to the action of light and air the deterioration is rapid, and in underground pipes the wires are never wholly dry, nor are they wholly under water. Their life, under such conditions, is from 12 to 15 years, but is much less when high E.M.F.s are in use upon the circuits.

India-rubber-covered Wires.

The specific capacity of gutta-percha is 4·2, whilst that of india-rubber is about 2·94, and it would therefore appear preferable to use india-rubber-covered wires, but in cables it is found that the difference in capacity between cores of the same dimensions does not usually exceed 10%. Also, the dielectric strength of rubber is considerably greater than gutta-percha, or, in other words, a given thickness of rubber will withstand a difference of potential between the opposite faces which would break down an equal thickness of gutta-percha. It has, however, been found that the life of india-rubber-covered wires laid in pipes is less than half that of a gutta-percha-covered wire, and consequently its use has been entirely abandoned.

Many proposals have been made for the substitution of rubber and percha, but so far without conspicuous success.*

AIR-SPACE AND PAPER-CORE CABLES.

The air-space and paper-core cables which have been so extensively used during the past few years have the merits

* See leading article "Submarine Telephone Cables" in the *Electrician* of September 2, 1904, p. 796.

of cheapness and less static capacity than gutta-percha-covered wires. For a given number of wires the cable itself is cheaper than the same number of gutta-percha wires, and, as it occupies far less space, there is a large saving in the number of conduits needed. The nett result is that the cost per circuit is one-third to one-fourth of that of a circuit in a G.P. cable.

The carrying capacity of a pipe is proportional to the square of its internal diameter, but the design of the cables somewhat modifies this statement, since there are certain constants, such as the thickness of the lead covering, to be considered. It may, however, be interesting to compare the numbers of conductors of various types which may be accommodated within 2, 3, and $3\frac{1}{4}$ inch pipes, and the following table is therefore added :—

	G.P. wires. 40 lb. conductors.		Number of wires in one paper-core or air-space.					
Type of pipe.	Single wires.	Quadruple cables.	Screened 40 lb.	20 lb. conductors.	40 lb. conductors.	100 lb. conductors.	150 lb. conductors.	200 lb. conductors.
2″	40	10	61	122	74	38	30	24
3″	80	20	108	612	216	122	74	74
$3\frac{1}{4}$″	92	23	156	612	254	150	96	74

The cables consist of conductors contained within a seamless lead sheathing, and separated from each other by air and paper. The "air-space" cable is one in which the maximum amount of air space is allied with the minimum thickness of the paper, whilst "paper-core" cables are those in which the insulation is very largely of paper. For telephone distribution work a paper-core cable is employed, since the cost of the cable would be very greatly increased by enlarging the space occupied by each conductor. Again, the screened cable is of the paper-core type, since it is necessary to form a continuous copper sheathing around each conductor.

Cables of the two types described are frequently spoken of as "dry-core," "paper," or even "lead" cables, but the designations indicated above appear to be more accurate.

It will be obvious that the substitution of air for gutta-

percha as the dielectric reduces the static capacity of the wires, and even in paper-core cables (see page 768) a very large reduction takes place. The capacity of paper-core *twin* cable conductors varies from ·08 with 20 lb. conductors to ·1 m.f. per mile with conductors weighing 100 lbs. or more per mile.

The most serious danger which menaces these lead-covered cables consists in the corrosion of the sheathing, but whether this will prove of vital importance is yet too early to say. It will be obvious that from the very design of the conduits and boxes it is impossible to keep the pipes quite free from water. The water which finds its way into the pipes frequently contains active chemical substances in solution which gradually destroy the sheathing—in fact, there is evidence to show that in some cases a slight amount of chemical action commences even before the cable is pulled into the pipes, but this may be entirely avoided by the application of grease immediately after manufacture. Since the cast-iron pipe and the lead sheathing with a certain amount of impure water form a voltaic couple, corrosion may also arise from this source, but by far the most serious trouble is produced by leakage currents from the uninsulated return circuits of electric tramways. The precautions to be observed are as follows:—

(1) To pack the box-lids with tarred pipe yarn and a mixture of crane grease and whitening so as to secure a water-tight joint.
(2) To use large quantities of petroleum jelly when drawing in the cables, and thus to provide a protective covering.
(3) To electrically connect the various lengths of iron pipe where they are broken by boxes or other jointing chambers, and to connect both the pipes and the cables which they contain to efficient earths at suitable distances apart.

If the pipes are perfectly dry or if the cables are well covered with grease, chemical voltaic, and electrolytic action is excluded, but in practice these conditions cannot always be attained. The object in bonding the pipes is to prevent any current circulating in the pipes from passing through the cables at the points where the line of pipes is broken by

a jointing chamber, for it will be obvious that if moisture is present at these points electrolytic action must inevitably result. In some cases the effect has been of sufficient magnitude to entirely destroy the lead sheathing (by converting it into carbonate of lead or white lead) and thus exposing the paper insulation. In order to prevent electrolytic action due to leakage currents in the cable sheath, where they enter or leave the cable, efficient earth connections at suitable points are provided, and it is believed that these remedies will obviate further serious damage.

The method of bonding the pipes together is illustrated in Fig. 446. The spigot end of all new pipes is of slightly increased length so as to enable a suitable bolt hole to be made. A thin lead sleeve is slipped over the slightly conical head of the G.I. bonding bolt, whilst a washer, recessed to receive the lead strip used for electrically connecting the successive pipes across the jointing chamber, is placed beneath the nut. When this nut is screwed down the lead between the pipe and the head of the bolt and that between the washer and the top of the pipe (which is, of course, previously scraped quite clean) is subjected to compression, thus establishing an intimate electrical contact between the pipe and the lead strip. For bonding the pipes which have already been laid, Bullers' patent clips are employed; they fit over the outside of the pipes and serve to maintain the lead connecting strip in firm and complete contact. Where there are several pipes in the one box, the ends of all the pipes are electrically connected together, and also to the various cables which they contain, by lengths of lead strip. It should be pointed out that the ordinary leaded joint (see Fig. 433) between the various pipes forms a fairly satisfactory electrical joint, notwithstanding the two coatings of Angus Smith Compound which intervene

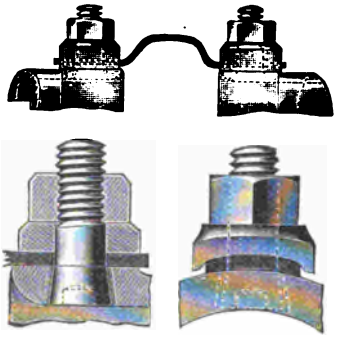


FIG. 446.—Bullers' bonding bolts.

between the socket, the lead, and the spigot of each pair of pipes.

Inductive Disturbances.

The inductive interferences between parallel single wire telephone circuits led to the universal adoption of metallic circuits. Owing to the unsensitive character of telegraph, in comparison with telephone, receiving apparatus no difficulty was experienced with single wire telegraph circuits until they were brought into close proximity for long distances in air-space cables. In order to appreciate the nature and efficiency of the remedy it is necessary to investigate the typical conditions under which static and dynamic induction occur.

Consider three insulated brass spheres *A*, *B*, and *C* occupying the relative positions indicated in Fig. 447, *B* and *C* being joined by a wire. The sphere *A* is positively charged by connecting to it the positive pole of an earthed battery. The positive charge upon *A* acts inductively upon *B*, with the result that a certain quantity of positive electricity is repelled along the wire to *C*, which becomes positively charged. The action of *A* upon *C* has been ignored since its effect is merely to slightly reduce the quantity of electricity flowing from *B* to *C*. When *A* is discharged, the negative charge upon *B* is no longer held by the positive charge upon *A*, consequently a current flows from *C* to *B*, and both spheres resume their normal or uncharged conditions.

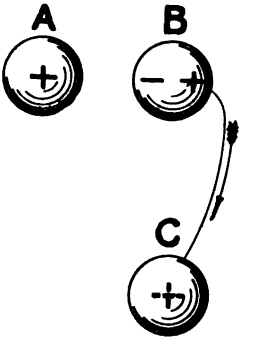


Fig. 447.—Electro-static induction.

Consideration will show that every change in the charge *A* produces a current between *B* and *C*. An increase in the positive charge or a reduction of the negative charge causes a current to flow from *B* to *C*, whilst a reduction of the positive or an increase in the negative charge produce a current from *C* to *B*. The induced current only flows whilst the charge upon *A* is varying.

The connection of an earthed battery to the disconnected line *A* (Fig. 448) produces currents through the ends of the

earthed circuit *B* which is parallel to it. The line *B* becomes negatively charged by the repulsion of a certain quantity of electricity to earth at either end of the circuit. A reversal of the battery, of course, produces a current flowing into the wire from earth at each end. If a relay is joined up at each end of the earthed circuit, and the disconnected wire is joined to a double current set, the signals sent on the key may be read upon the two relays, by carefully adjusting them to neutrality. For example, suppose that the letter "*T*" is sent. The spacing current charges the disconnected circuit negatively, which causes currents to flow from earth through the relays into the line, so causing the tongues to go over to *S* or leaving them in that position if already upon the left contacts. The

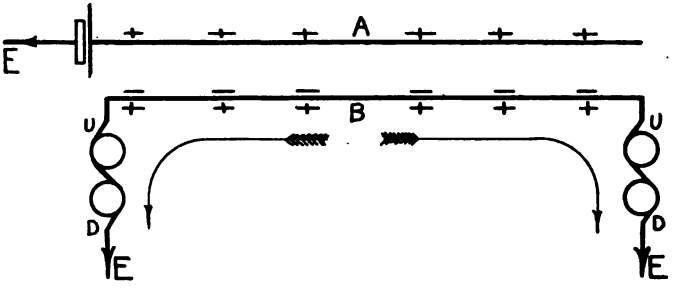


FIG. 448.—Electro-static induction between two telegraph circuits.

depression of the key for the dash charges *A* positively and currents flow through the relays, in the direction *U* to *D*, to earth at each end. This commences the mark which is not stopped until the key is released and momentary currents again flow through the relays.

This is a typical case of electro-static induction, and it is to this effect that the whole of the serious trouble is due.

Electro-magnetic, or dynamic, induction is due to the fact that the lines of force generated by a current in the first circuit cut the conductor, and so induce a current in the second.

In Figs. 448 and 449 the relays are all shown with their "up" sides joined to line, whereas in practice the relay at one end would have the "up" side to earth. It will therefore be realized that the inductive effect would be such as to produce reversed signals at the down station.

Two parallel earthed circuits are shown in Fig. 449, and this represents the case which arises in practice. When the battery is connected to circuit *A* a current begins to pass along the line, and the wire is charged as indicated by the shaded triangle. Now the charge upon *A* produces momentary currents in the directions shown by the double arrow-heads, but as charge is larger at the sending end the current produced through the relay on the left is greater than that through right-hand relay, the actual difference being in the ratio of two to one.

Whilst the current is attaining its full value the concentric lines of force round the full length of *A* cut through

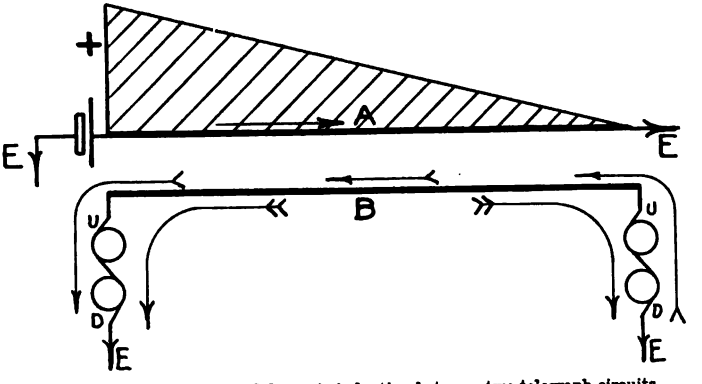


FIG. 449.—Electro-static and dynamic induction between two telegraph circuits.

the circuit *B*, generating an E.M.F. in the direction shown by the single arrow-heads. The value of the resulting induced current is, of course, equal at all parts of the circuit.

At the left-hand side of the circuit the dynamic and static effects add together, but at the other end they oppose, with the result that this end of the circuit may be practically unaffected, whilst pronounced currents are produced through the left relay whenever the position of the key upon *A* is altered.

By considering a few typical cases it can readily be shown that the interference by induced currents is much greater at the end nearer the sending station than at the further end.

In the London-Birmingham underground cable the inductive effect of the circuits upon each other is so great as to render Wheatstone working upon single wires quite impracticable, and this notwithstanding that the wires are crossed at frequent intervals so as to prevent any two circuits from running side by side for any considerable distance. The wires in this cable are twisted in pairs, and for each Wheatstone circuit a twisted pair of wires is employed, but this is not a very serious matter, since a key worked duplex circuit is superimposed upon each Wheatstone circuit, and two circuits are thus obtained from the pair of wires. (See appendix C.)

By twisting the wires in pairs the inductive effect of each wire is balanced by the opposite effect of its partner, whilst no effect can be produced upon the twisted circuit, owing to the two wires uniformly changing their positions with such frequency that the inductive effects in each are equal and balance.

A long series of very exhaustive experiments proved that a certain

Fig. 450.—Quadruple pair air-space cable.

Fig. 451.—Section of a quadruple pair cable.

amount of inductive interference occurs between two neighbouring pairs of twisted wires of equal lay running together for a considerable distance. This induction is of a serious character when the pairs of wires are used for telephone circuits, but the sphere of disturbance due to each twisted pair is limited to the two, or in some cases three, pairs next to it upon either side. This defect has been remedied by varying the lay, *i. e.* the length taken for a complete twist. With 20 lb. conductors, the successive conductors in the outer layer have lays of 3, 4, 5 and 6 inches respectively, whilst with 100 lb. conductors the lays are 7, 8, 9 and 10 inches.

Screened Cable.

As stated, the use of a metallic circuit for the high speed wires eliminates all trouble due to inductive interference between the telegraph circuits contained within a long cable. In order to avoid the use of two conductors for each Wheatstone circuit, and to effectually prevent inductive disturbances, even when the circuits run together in the same relative positions for long distances, the "paper-core screened single conductors" cable was specially designed.

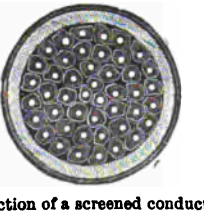


Fig. 453.—Section of a screened conductor cable.

Fig. 452.—Screened conductor cable.

The conductor, of 40 lb. copper, is first covered with

three wrappings of paper, the first of which may be either spiral or longitudinal, but the other two are invariably applied spirally. The spiral wrappings are applied so as to form a helical air space throughout the length of the core. The conductor thus insulated is then enclosed in a final wrapping of paper forming a closed helix without overlap. Over this is laid a helical winding of copper tape 300 mils wide and 3 mils thick, with an overlap 90 mils wide. The over all diameter of each completed conductor is 160, 180, or 200 mils, according to the type of cable required. For instance a cable containing 40 conductors is made up of 1, 6, 12, and 21, cores in the centre, 1st, 2nd, and outer, layers respectively. The outer layer conductors are in this case 160 mils in diameter, whilst all the remaining cores have a diameter of 200 mils. The capacity of the 160, 180 and 220 mil cores are respectively ·15, ·135 and ·125 m.f. per mile, whilst the minimum insulation is specified as 5000 megohms per mile at 50° F. after one minute's electrification.

The whole of the cores are laid together, and a seamless cylindrical sheathing of lead, at a temperature of 600° F., is applied to the cable. The thickness of this sheathing is from 130 to 150 mils, with an external diameter of 1·65 inches.

The cable is made in the lengths required for pulling in between the various boxes along the route upon which it is to be used. The two ends of the cable are sealed by soldering lead caps on to the ends of the sheathing, and the completed length is wound on to a wooden drum ready for delivery.

Although this description relates to a particular type of cable, it is typical of all, since the differences consist merely in the number and arrangement of the cores.

A cable having 45 40 lb. conductors is illustrated in Figs. 452 and 453. A 40 lb. conductor core having a diameter of 230 mils gives a capacity of ·095 m.f. per mile. Cores having 70 lb. and 100 lb. and even larger conductors are used, but they are very often specially designed to meet the particular circumstances under which they are to be employed. A 70 lb. core with a total diameter of 225 mils and a 100 lb. core with a diameter of 240 mils each give a capacity of ·125 m.f. per mile.

The substitution of paper and air for the gutta-percha

covering of the old type of wire reduces the capacity, and increases both the insulation resistance and the dielectric strength of the core. The addition of the copper tape screens the conductors from inductive interference, and so obviates the difficulty which arose with the ordinary type of air-space cable, when used for telegraph circuits.

The copper tape forms a continuous conducting tube around the wire, and as this tube is earth-connected, either by direct contact with the lead sheathing or indirectly by the tapes of the other cores, it will be obvious that electro-static induction between the wires cannot occur. Firstly, Faraday's experiments showed that variations in the differences of potential existing or produced between conductors within a metallic covering produce no effect outside that covering. Secondly, any source of inductive disturbances brought to bear upon a screened conductor produces the whole of its effects upon the copper tape. The magnetic lines of force induce currents along the tape covering the wire, and as this path is highly conductive, practically the whole of the energy is absorbed by it. In order to produce an inductive effect, currents must be generated in the tape of the disturbing wire and also in the tape of the disturbed wire before the second conductor is reached. It will therefore be realized that the energy available is exceedingly small, and in practice it may, without serious error, be considered to be *nil*.

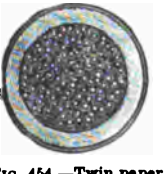


FIG. 454.—Twin paper core cable.

FIG. 455.—Section of a twin cable.

This type of screened cable represents the standard practice of the Post Office for telegraph

circuits, and circuits of any description may be worked in any position in the cable, and may run together in the same relative positions for indefinite distances without a trace of inductive disturbances.

A large quantity of cable consisting of single conductor lead-covered wires contained within a spiral wrapping of ozokerit tape is in use at the present time. This cable proved unsatisfactory, largely on account of the joints becoming defective by reason of their somewhat fragile character, and this led to the design and introduction of the type just described. The lead sheathing over each conductor serves precisely the same purpose as the copper tape in the screened conductor cable.

There is a very large number of types of cable used by the Post Office, and as telegraph and telephone circuits are frequently contained within a single cable it has been thought desirable to briefly indicate a few of the prototypes.

Air-space cables. Twin types.—In every case the variable lay principle is adopted, and the various cables differ solely in the number of pairs, gauge of the conductors, and consequently in the diameter of the cable (Figs. 454–455).

Air-space cables. Quadruple pair type.—Four pairs of wires are twisted together round a jute centre or core and the cable formed of the required number of these quadruple pairs (Figs. 450 and 451). The lay of the four pairs of wires in each set is varied, as also is the lay of the quadruple cores. The advantage gained by this construction lies in the fact that telephone trunk line superimposing is practicable upon the quadruple pairs, and that the wires in each 8-wire core may be combined to form heavy-gauge circuits.

Composite cables.—The various methods of arranging the conductors are sometimes utilized to provide for special requirements. For instance, 42 wires of 150 lb. and 48 of 100 lb. gauge are combined to form a cable in the following way. A central pair of 150 lb. wire forms the core, and around it are placed four paper-wrapped cables, the interstices being filled by single, or as they are termed "worming pairs." Each of the paper-wrapped cables consists of four quadruple pair 150 lb. conductors with four twin 100 lb. conductors filling the spaces between the 150 lb. pairs—the latter having a large air space.

Again cables are formed having a core of multiple twin or quadruple pairs surrounded by screened conductors for telegraph circuits. For example, one such cable contains 8 150 lb. and 56 100lb. wires arranged in quadruple pairs together with 30 100 lb. and 7 40 lb. screened conductors. The centre is formed by one 150 lb. quadruple pair core around which are placed 7 100 lb. quadruple pair cores, whilst the outside layer is formed by the 30 100 lb. screened conductors, between which and the 100 lb. quadruple twin cores are the 7 40 lb. conductors.

Multiple twin cables.—In these cables the conductors are first twisted in pairs, and two pairs are then twisted together. A second set of two twisted pairs is twisted with the first set. In some cases the complete group is twisted with a similar one. The object attained is that the conductors may be bunched to provide a circuit of heavier gauge. For instance, with 40 lb. conductors the equivalent of 80 lb. and 160 lb. is obtained by placing the wires of one and two pairs respectively in parallel to form one wire of the new circuit. The capacity is increased by bunching but in a smaller ratio than the resistance is reduced, hence the K.R. of the bunched circuit is less than that of a single pair. The variable lay principle is adopted to prevent overhearing, and the length of the lay is distinguished by the colour of the paper wrappings over the 2, 4, 8, and 16-wire cores, the A and B lines being distinguished by the colour of the spiral wrapping of thread. Since the conductors are all twisted up in the manner described, the bunched wires are still twisted together and inductive disturbances eliminated. By superimposing it is possible to obtain 15 circuits from each 16-wire core.

Pulling in G.P. Cables.

The joints between successive lengths of gutta-percha-covered cables are invariably made in joint boxes. Upon some of the older routes the boxes were buried beneath the roadway, and whenever it was necessary to attend to the wires the ground had to be opened before the chequered iron cover of the box could be raised to afford access to the wires. This proved somewhat inconvenient, and consequently boxes having lids flush with the pavement are now invariably employed.

The cable is usually made up in lengths of about 400 yards, whilst a box is placed every 100 yards along the route. The cable is taken to the central box of the section into which it is to be drawn, and is placed in the form of an elliptical coil with a major axis of eight feet and a minor axis about two feet, upon a clean tarpaulin sheet adjacent to the box. One half of the cable is drawn through the pipes and the nearer box (100 yards distant) where it is carefully coiled as before upon a tarpaulin. The 100 yards of cable is then drawn into the next section, whilst the 200 yards at the central box is dealt with similarly. The procedure indicated, whilst limiting the length of cable pulled through the pipe at one operation to 100 yards, at the same time necessitates but one joint every 400 yards. As the jointing of the cables is somewhat costly, and as every joint is a possible weak spot in the insulation, the advantages gained are of serious moment.

The cable is pulled into the pipe by means of the iron wire which is threaded through the pipes when laid. Where a wire is not available, sweeps' rods are employed just as described in the section upon air-space cable work.

Jointing G.P. Wires.

The jointing of the wires requires a considerable amount of skill, and it is necessary that the men engaged upon the work should receive a certain amount of training before undertaking it. The physical qualifications required by jointers are personal cleanliness, patience, and care, but as these are the characteristics of the average lineman little need be said upon this score.

The method of jointing two gutta-percha covered wires is as follows :—

1. The coverings of the two wires are stripped off for a distance of 2 inches, and the wires are scraped clean and bright.
2. The wires are crossed about half-an-inch from the end of the G.P. covering and then twisted together with pliers.
3. It is essential that the two wires shall be twisted equally so that the joint may have the minimum diameter consistent

with a tight and firm contact between them. The twist extends up to the points at which the insulation begins.

4. The twisted joint is soldered and then shaken to remove all superfluous solder, care being taken to leave neither "tear drops" nor fine points of solder upon the conductor.

5. The joint is then cleaned to remove all traces of resin or dirt and the ends of the G.P. covering are also cleaned.

6. The G.P. covering is warmed by the flame from a spirit lamp for a distance of about 2 inches upon either side of the twisted joint, and is then worked with the fingers until the whole of the joint is evenly covered.

7. The joint between the two sides of the insulated covering is again carefully worked over and the joint allowed to set.

8. The portion of the G.P. over the twisted joint is then

FIG. 456.—G. P. joint (cut open).

roughened with a blunt knife and a thin coating of Chatterton's compound is applied.

Chatterton's compound is manufactured in sticks, and consists of three parts gutta-percha and one part each of resin and Stockholm tar, the parts being by weight and not by volume. It is dealt with in similar fashion to gutta-percha, and by gently warming it may be made to assume a soft and plastic form.

9. A strip of G.P. sheet 1 inch wide and 6 inches in length is thoroughly warmed on both sides and is then pressed on to the centre of the joint and wound into a coil.

10. This coil is then worked in both directions along the joint until it extends about $4\frac{1}{2}$ inches.

11. The points where the new and old G.P. meet are carefully warmed and worked again.

12. Finally the joint is smoothed over with wet and soapy hands.

A section of a completed joint is shown in Fig. 456.

In making the joint care must be taken not to "nick"

the wire when removing the G.P. covering, since this invariably leads to a fracture when the wires are handled. Also the lamp must be very carefully applied in order that the gutta-percha may be rendered plastic without any trace of burning. By carefully working the insulation together all air is excluded and a homogeneous joint results. But even then, the joint may be bad owing to the G.P. being unevenly worked round the wire, thus leaving a thin covering at one point and a correspondingly heavy covering opposite. Decentralization of the conductor, or eccentricity as it is more usually termed, is a fault which rarely occurs with a well-trained jointer. Again, the excessive use of moisture in the final operation is often productive of trouble, but, after all, the various defects enumerated are only what would naturally be expected when skilled work is entrusted to inexperienced or unskilled persons.

When a person has been selected for jointing work the principles should be explained and he should then be set to make numbers of joints between odd pieces of wire. These joints should be tested by immersing them in water for 24 hours, after which they should be tested with a high voltage. Some of them should be cut open to see whether the twisted joint is precisely in the centre of the insulation and to observe if any air holes have been left. It is only when the man ceases to make *any* defective or doubtful joints that he should be permitted to undertake jointing work upon actual circuits.

Renewal of G.P. Cables.

The wires along any particular route require occasional renewal and it may also be required to add to their number. Needless to say this work must be accomplished with the minimum amount of interruption to the circuits working through the wires. The opportunity is usually taken, when renewal becomes necessary, to add sufficient wires for the probable requirements of the immediate future. Briefly, the system consists in cutting in each new length of cable into the old cable and then drawing the new one in by pulling the old one out. The old cable is then cut out, and if discretion is exercised there is no reason why the interruptions should cause serious inconvenience.

It is frequently found that cables which have lain undisturbed for several years are firmly attached to the pipe, largely due to the rusting. The first operation is, therefore, to loosen the wires by pulling or twisting them, or if this fails the ground may be opened at an intermediate point and an attempt made upon the shortened sections. It is, of course, essential that force, likely to break the wires and so interrupt the circuits, must not be used, and here a considerable amount of judgment, which can only be obtained by practical experience, is required.

Having loosened the old cable, the new length is coiled upon a tarpaulin at the middle box and the ends are bared. The insulation is then removed from one of the old wires and the two ends of one of the new wires are connected upon either side, the old wire is cut and the two joints completed in a safe but temporary manner with either G.P. tissue or Chatterton's compound. This operation is repeated until the whole of the circuits are working through both the old and the new cable.

The joints are next protected by a wrapping of canvas, after which the new cable is pulled in by drawing the old one out at the nearest boxes upon either side. The operation is then repeated from the end boxes in the manner previously described save that the old cable takes the place of the draw wire. When this has been done the old cable lies upon the pavement at the two end boxes, and it is then necessary to remove it from the circuits. As it is impracticable to trace the wires through by hand, a detector and battery are used as follows :—

The junctions between the old and new wires are first of all bared, but are kept apart so as to avoid contacts. Similarly where the other end of the old cable joins that in the pipes ahead, the insulation is stripped off for a short distance. One side of a 2-cell dry battery, joined in series with the "quantity" (or low resistance) coil of a Q and I detector, is then joined to any one of the wires whilst the free end of the galvanometer is connected to a lead with which each wire is successively touched, at the junction between the new and the old cable, until a full deflection is observed. The two wires producing the deflection are then joined straight through, thus cutting out the old wire. This operation is repeated until the whole of the wires have

been jointed through, and the whole of the old cable wires cut out. It should perhaps be pointed out that the quantity coil of the detector will not produce a deflection with the current shunted across the ends of the old cable and that practically no deflection is produced by the 2-cell battery through the earthed ends of any two circuits, whereas a strong deflection results when the circuit is completed through the 400 yards of wire (about 5$^{\omega}$) in the old cable.

Since this process entails momentary contacts whilst finding the corresponding ends of the old cable, this part of the work is only done during slack periods of the day when the interference with the circuits is not of serious consequence.

Each wire is numbered in each box so that any particular wire may be identified at any point. This is effected by small leaden labels, with numbers stamped upon them, bent round so as to encircle each wire. The wires in each quadruple cable are also enclosed in split ferrules of lead in order that the relative positions of the four wires may be observable even when the taping has perished. This is of course, important in the case of telephone circuits, since inductive disturbances are only obviated when each pair of wires occupy diagonal positions in the cable.

Should it be necessary to identify any wire which is not numbered in the boxes the wire is found with a compass, and under no circumstances are the wires pricked, since this leads to faults. It is quite impossible to make a perfect repair at a point where the insulation has been pierced, save by baring the wire and making a joint as previously described.

Numbering Wires.

As it is frequently necessary to identify and number the wires at the two ends of a cable to correspond it will probably be of service to indicate precisely how this is accomplished. One wire between the two points is employed as a return path and a galvanometer is joined in series with it at each end, whilst a 2-cell dry battery is included at one end. This wire may be any one of the wires in the cable, or it may be dispensed with by earth connections. The battery is connected to the wire it is desired to make

No. 1, and the man taps round the wires until a deflection shows that this wire has been "found." He then gives three beats by breaking and making the connection three times, after which the wire is held on until the man at the distant end has replied with three beats. Both then label the wire No. 1, and the battery is joined to the second wire, and the process is repeated until the whole of the wires have been numbered.

Cable Lengths.

It is economical to manufacture lead-covered cables in long lengths, but the length which may safely be placed upon a drum for transportation should not be such as to cause the weight of the filled drum to exceed three tons. When this limit is passed the weight of the drum is likely to damage the paving along which it may have to be rolled. The length of cable which may be pulled into the pipes in one operation depends upon the weight of the cable per unit length, its diameter, and also upon the character of the route. Where the route is either straight or the curvature slight, from 100 yards with large to 250 yards with small cables may be safely pulled in in a continuous length. For instance, a $\frac{14}{20}$ (*i. e.* a 14 wire 20 lb. conductor) cable, diameter $\frac{7}{10}$ inch and weight per yard 3·16 lbs. would be pulled in in lengths of 222 yards or more, whilst a $\frac{216}{40}$ diameter 2·85 inches and weight 27·4 lbs. per yard could only safely be pulled in in lengths of 152 yards.

Pulling in Lead-covered Cables.

It will now be possible to follow the various operations involved in pulling in the successive lengths of lead-covered cables.

When a draw wire has been provided, as explained on page 744, this is used for pulling in the rope. If there is no draw wire sweeps' rods of special construction are pushed through the pipe. These rods are of bamboo, and are provided with a screwed brass socket and trigger at one end and with suitable screwed fitting at the other. A rod is passed into the pipe, and a second length screwed on, and automatically locked by the spring trigger which prevents the rods from unscrewing whilst being pushed

through the pipe. As each rod is pushed up the pipe another is added, until finally the two jointing chambers are linked by a continuous length of rods. The rope is next attached and pulled through by withdrawing the rods.

It will, of course, be obvious that in these, as in the subsequent operations, it is necessary to rail off a suitable space for carrying out the work in order that pedestrians may neither impede it nor may they run any risk of injury. Where holes are left the guards must be supplemented by lamps at night.

The next operation has for its object the cleaning and testing of the pipe into which the cables are to be drawn. The rope is joined to a mandrel, a circular brush about 12 inches long and a piece of cable roughly 3 feet in length, and of a diameter very slightly less than that of the pipe. For example, with a 3-inch pipe a length of $\frac{2\,1\,6}{4\,0}$ cable would probably be used. This piece of cable is painted over, and the whole train followed by a second length of rope is pulled through the section. The test cable is carefully examined for any trace of damage, and when this occurs the defect is, of course, remedied before the new cable is pulled in. The position of this defect is usually apparent from the extra stress which has to be exerted to pull the test cable and mandrel past it.

The rope used for pulling in the cable is usually of the 3-inch size (*i.e.* the circumference is 3 inches), and has a breaking stress of about 35 cwts, which ensures that it may with safety be used in all cases in which the stress does not exceed 7 or 8 cwts.

The drum containing the length of cable is conveyed upon a low wagon or "float" to the box from which it is to be paid into the pipe. The battens are removed, the drum rolled into position, and a steel spindle passed through the holes in the centre. It is then raised upon lifting-jacks sufficiently to permit it to revolve freely. The manufacturers usually seal the cable by soldering circular discs of lead to the ends, and as this is scarcely calculated to withstand the stress placed upon it by the clip, it is advisable to remove it and make up the end in a stronger manner. When this has been done the clip is fixed on to the cable.

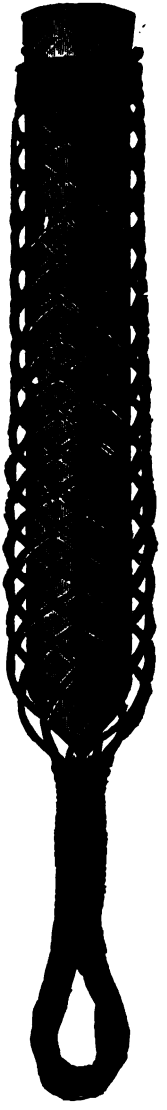


Fig. 457.—Cable grip.

Before proceeding further, it should be explained that two forms of clip are in use. The older form consists of two semicircular plates united by a stout loop. This is placed over the end of the cable, to which it is secured by screws driven through the cable and tightly screwed up between the sides of the clip, so as to grip the cable. In order to ensure that the screwholes shall not admit moisture the end of the cable (with the clip affixed) is dipped into melted paraffin wax and is allowed to remain immersed sufficiently long for the interstices to become thoroughly filled up and more or less impervious to moisture. When this operation has been carefully performed it will be found that, when the end is finally cut off and opened, the end of the cable is thoroughly impregnated with wax.

The second and more modern type of clip, illustrated in Fig. 457, is termed a "cable grip," and is constructed upon the principle of a well-known puzzle toy. The lead sheathing at the end of the cable is beaten down on to the conductors with a boxwood dresser so as to prevent the lead sheathing from taking the whole of the stresses which result during the pulling-in process. The grip is passed over the prepared end of the cable to which it is lashed as indicated. The effect of stress applied to the loop is merely to tighten the grip of the latticed wires upon the cable. In this way the need for cutting away the waxed end, which is also damaged by the clip screws, is obviated, and the saving of even a foot of cable at either end of each length represents a considerable sum of money where long lengths of large cable are concerned. A suitable form of sleeve has recently been designed for protecting the wire cable grip, which is

naturally subject to considerable wear by friction with the pipes through which it is pulled.

The clip, having been attached to the cable, is joined to the pulling-in rope by means of a Keystone connecting link (Figs. 458 and 459) connecting the loop of the clip and the ring upon the rope.

Whilst these preparations are being made the winch is placed in position and the rope given three or four turns round the barrel. Where the pulling in is done from a manhole a snatchblock attached to the rings in the floor

Fig. 458.—Connecting link, open.

Fig. 459.—Connecting link, closed.

(see Fig. 460) is placed upon the rope to prevent chafing upon the edge of the pipe and manhole entrance. In Fig. 460, a winch worked by a small water-cooled petrol motor has been shown, but this arrangement has not so far come into use in this country, although motor winches are quite commonly used in America.

The drum is now twisted and the cable bent into a curve of wide radius, and the end placed within the pipe, the slack rope being taken up from the distant end. The actual pulling in of the cable now commences, and with large cables four men are required for turning the winch. Men are deputed to carefully revolve the drum and bend

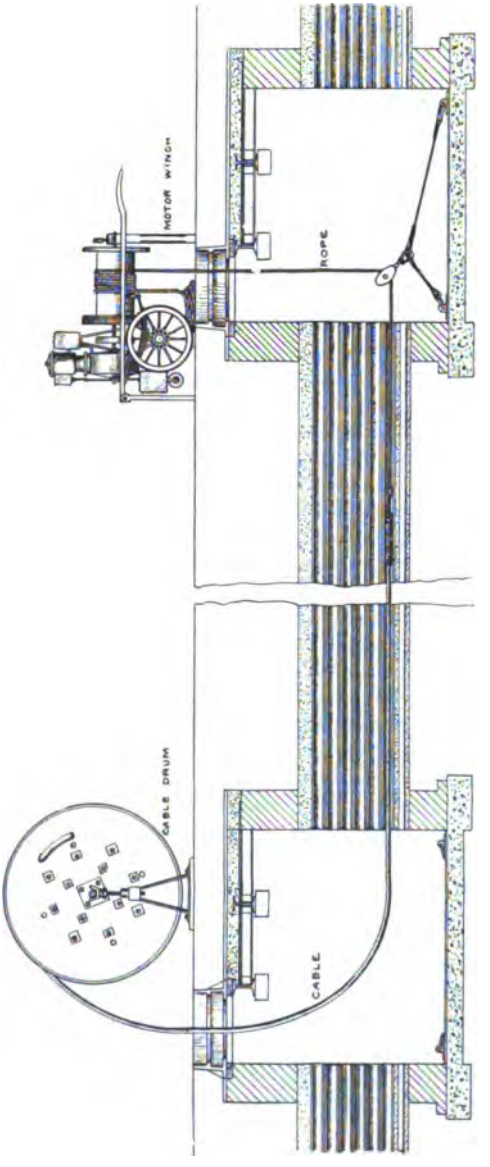


FIG. 460.—A dry core cable in course of drawing-in by means of a motor winch.

the cable so that it enters the pipe without injury to the sheathing.

In all these operations the guiding principle is to deal with cable just as though it were a hollow tube of lead.

As the cable passes into the pipe it is heavily anointed with petroleum jelly, which acts as a lubricant, thus reducing the friction between the cable and the pipe. Since the clip end of the cable has to be drawn through the whole length of the pipe, whilst the last yard of cable is only drawn through one yard of pipe, the quantity of petroleum jelly spread upon the cable is gradually reduced as the pulling in proceeds.

When the cable has been pulled in as far as possible, *i. e.* when the end of the rope reaches the snatchblock, the length of cable projecting from the pipe is usually insufficient to admit of jointing and it is therefore necessary to remove the clip and obtain a fresh purchase upon the cable. This was formerly accomplished by lashing the pulling rope to the cable as near to the pipe as possible, but an open-ended racking grip is now used for the purpose. This grip is of the same general pattern as that previously illustrated, but the wires terminate in two side loops. The pulling-in grip is removed and the racking grip is then passed over the end of the cable, the two loops connected by a bolt, and attached to the pulling rope. In this way the extra yard or so of cable may readily be obtained, it sometimes being necessary to move the grip back once or twice to obtain the requisite length of cable in the jointing chamber.

After the cable has been pulled in, the clip is removed, and when of the old type in which the cable is pierced, this end is cut away and the cable re-sealed.

When the cable has to be pulled into joint boxes a snatch block or pulley is securely lashed to a balk of wood placed at the bottom of the box and wedged in position by timber placed along the floor of the box and held down by two upright pieces of wood bearing upon the two planks placed over the box to carry the winch. If this arrangement were not made it would be necessary to remove the box, open out the ground, and back-stay the winch in order to avoid a heavy upward pull upon the pipe.

In arranging the length of the cable drawn in, provision

must be made for the end damaged by the clip, and for a sufficient overlap for jointing. Usually one per cent. above the centre to centre mileage is an ample provision.

Other considerations being equal, it is preferable to pull the cable in in the direction in which the pipes are laid, *i. e.* in the direction of spigot to socket, since there is thus no chance of the clip wedging against the spigots.

Where there is a curve in the route the cable should be pulled in from the end nearest to the curve, since the shortest possible length of cable is thereby pulled round the curve. Again, it obviously requires less force to pull a cable through a pipe having a downward gradient than to pull it upwards.

It is always desirable to pull the various cables in in the same direction, so that the direction of the lay may be the same upon both sides of each joint.

Jointing Lead-covered Cables.

A gothic-shaped tent, consisting of canvas mounted upon a wooden frame, is erected over the box or hole in the ground where the joint is to be made, and in order to avoid any risk of fire, the spirit lamp used for soldering, etc. is held in position by springs and is surrounded by a metal shield which is secured to the tent. In the case of roadway manholes a circular guard is placed round the entrance, and, as a further precaution, a man is stationed by it during the whole of the time that it is open. Similar remarks apply to the execution of work of every description.

The cables are cut so as to leave the amount of overlap required for the joint. This varies from 10″ with very small, to 2′, or even more, with large cables. For instance, a $\frac{14}{20}$ cable would require 10″, a $\frac{74}{40}$, 15″, and $\frac{216}{40}$, 24″. First of all, the surplus length of cable is cut away and then the sheathing is cut rather more than halfway through by means of a knife, and a longitudinal cut from the end of the cable to the point at which the sheathing is to be removed is made. It is then *torn* away with the aid of a pair of pliers. The effect of this procedure is to form a bevelled edge upon the inner edge of the sheathing. This leaves the conductors upon each side exposed and of sufficient length to reach to the point at which the lead sheathing

ends upon the opposite cable. A lead sleeve of the requisite length and diameter is then passed over one end of the cable and pushed up the pipe so as not to impede the operations now to be described. In each cable the wires are separated, tied up in half layers and bent up at right angles to the cable. The jointing of the conductors then commences, starting with the lower wires in outer layer, then the lower wires in the next layer, and so on until the lower half has been dealt with. The upper wires are next jointed, but this time working from the centre outwards.

The method of jointing varies with the type of cable, and two illustrations typical of the rest will be given:— Firstly, a multiple twin cable, with conductors of 70 lb., 100 lb., 150 lb., or 200 lb. gauge, in which each wire is

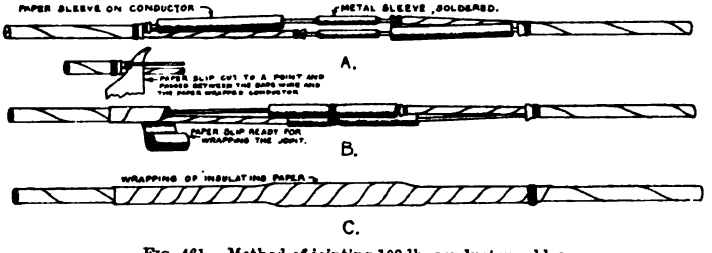


FIG. 461.—Method of jointing 100 lb. conductor cables.

loosely but completely enclosed within a paper covering served with a wrapping of thread, having a long lay. Secondly, a multiple twin cable, with 40 lb. conductors.

In the first case the spiral wrapping of paper which encloses both wires is tied and removed to that point; the two wires to be jointed are cut so that the conductors just reach each other, but the cut is made at slightly different points in the two wires. The paper is removed for a distance of 3″ on one side and 1″ on the other, and tied with linen thread, and a paper sleeve slipped over each. The ends of the wires are cleaned with glass paper, and split jointing sleeve of tinned copper placed over the two abutting conductors and soldered with resin as a flux. The second wire is then dealt with in similar fashion, the paper sleeves slipped over the conductor

joints, tied, and finally a spiral wrapping of paper completes the joint of the pair (Fig. 461).

With 40 lb. conductors the wires are cut, a paper sleeve passed over each wire, and then the conductor joint is made as indicated, being tipped with solder, and bent into line with the cable. The paper sleeves are pushed over and tied, thus completing the joint, as illustrated in Fig. 462.

In jointing 20 lb. conductors the two wires should be given three or four twists in a length of $\frac{1}{2}''$ with the paper insulation intact upon both wires. At the end of this preliminary twist the paper is removed, the conductors cleaned, twisted, and the surplus wire cut away, leaving $1\frac{1}{8}''$ of

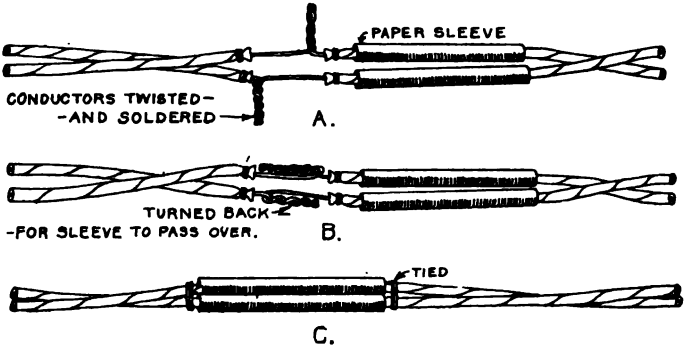


FIG. 462.—Method of jointing 40 lb. conductors.

twisted conductors. This twisted joint should be made without the aid of pliers since possible injury to the conductors is thereby avoided ; a skilled jointer is able to make the joint with ample tightness and security, and the practice of giving the joint a final twist with the pliers is to be strongly deprecated. The same method of jointing may be applied to 40 lb. conductors, but in this case larger paper sleeves must be used.

In all the later types of twisted cable the length of the lay is indicated by the colour of the paper wrapping which encloses each 2, 4, 8, or 16-wire core as the case may be, the A and B wires of each pair being distinguished by the colour (red for A and white for B) of the spiral wrapping of thread upon each single wire core.

Consideration will show that if the whole of the conductor joints are made at one point, the resulting joint will be of an extremely bulky description, and that the sleeve would take the form of a spheroid. This is, however, readily obviated by carefully spacing the joints, and, generally speaking, the diameter of the final paper wrapping does not greatly exceed that of the lead sheathing of the cable itself.

In some cables there is no serving of thread over each single wire, but the method of jointing is scarcely affected by this variation. It is, of course, essential that great care should be taken to join each pair of wires through to another twisted pair, since the result of a mistake is to destroy the advantage of the twist.

In variable lay cables some other precautions must be taken, for instance, in the multiple twin type, pairs having similarly coloured paper wrappings (signifying equality of lay) must not be jointed together nor must the pairs in one core upon one side be jointed to pairs in different cores upon the other side. These precautions prevent the differences in the length of the lay from affecting the resistance of the wires, whilst mixing the wires in the various cores would of course destroy the advantages gained by this form of construction. With quadruple pair cables similar precautions have to be observed, and where there are small gauge parallel worming pairs they must be crossed at each joint. As, however, these cables are exclusively used for telephone circuits further comment is scarcely justified in the present volume.

The paper sleeves are placed within a circular tin box resting within a bucket which is warmed by the flame of a spirit-lamp placed beneath it. This ensures that the sleeves shall be perfectly dry, since the bucket, etc., is kept under cover within the tent or manhole. When the last joint has been made the wires are thoroughly dried with a charcoal brazier, or, where the confined space would cause the fumes to be felt, hot powdered quicklime may be laid over the conductors. The test for dryness consists in holding a cold mirror upon the joint, which is not sufficiently dry until not a trace of moisture is observable on the glass.

The joint is then spirally wrapped with paper, but a hole is cut at the point below the air-nozzle upon the lead sleeve.

The lead sleeve is next pulled over the joint, and is secured to the sheathing upon either side by plumbers' wiped joints (Fig. 463). Incidentally it may be remarked that considerable skill and some experience is needed in this operation. The copper wires within the cable conduct the heat of the metal away somewhat rapidly, and there is therefore a risk of a defective joint. The "wipe" should be quite uniform and without any trace of eccentricity, and, of course, perfectly homogeneous. The heat applied during the "wiping" usually expels any remaining traces of moisture through the open air-nozzle.

Joint Testing and Dry-air Plant.

The wiped joint is tested by means of a portable desiccator mounted upon a truck. It comprises an air-pump worked by a suitable handle or in some cases by a small petrol

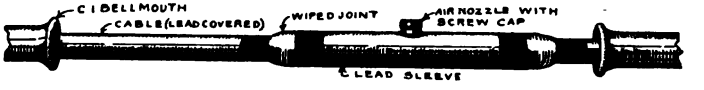


Fig. 463.—Completed joint.

motor. This draws air from the atmosphere, and finally pumps it through cylinders containing calcium chloride into the cable which is connected to it by means of a length of flexible tubing screwed on to the air-nozzle. The joint is smeared with soapsuds or glycerine, and the pump is worked until a pressure of 20 lbs. to the square inch is indicated upon the gauge. The joint is meantime closely examined for any trace of air-bubbles, the presence of which would indicate a defect in the wipe. This test is a severe one, and it may be said that a defective joint cannot possibly be overlooked. The opening of the air-nozzle is next closed by soldering on a tinned disc, and finally screwing the air-nozzle cap on, so completing the joint.

In every case in which the cable has been subjected to exceptional stress whilst being drawn in, or where there is evidence to show that the lead sheathing has drawn, a test is made to ascertain that the lead is unfractured. The pressure is worked up to 20 lbs. per square inch and the pressure gauge carefully watched to see that, after pumping

has ceased, the pressure does not fall. It may be mentioned that where the Post Office provides cables for the National Telephone Company the latter test the length of cable by means of a desiccator. The pressure is raised to 20 lbs. throughout the cable as shown by the pressure gauges at each end. The cable is then left for twenty-four hours and unless the pressure is then at least 18 lbs. the cable is considered defective and the source of leakage traced.

A defect in the sheathing would be indicated by a leak which occurred whilst the whole of the joints had been found to be perfect. By successively claying up the space between the cable and the pipe at both ends of each section and by making a pin-hole through one side of the clay and covering it with glycerine or soap-suds the section in which the fault exists will be made apparent by the leakage of the air, pumped into the cable, through the pinhole in the clay.

If the joint test is made by filling the cable to a pressure of 20 lbs. and successively examining the various joints, any leakage will be shown by a fall of pressure.

The advantage of the dry-air plant lies not only in joint testing, but also in the fact that any trace of moisture may be expelled by pumping dry air through the cable. This is the object of the calcium chloride, which is highly hygroscopic, and serves to remove every trace of moisture from the air which passes over it. Of course, it is necessary to occasionally renew the calcium chloride, but this is requisite less frequently than would be expected.

When desiccating a cable it is best to restrict the rate at which the air passes through the cable, and this may readily be accomplished by fixing an escape valve to the air nozzle at the end of the section and setting it to blow at 8 lbs. It is preferable to place the desiccator in the centre of the section to be dealt with and to blow each way rather than to place it at one end. All cable heads are provided with a gas plug, by removing which and coupling up an escape valve the process of desiccation may be carried out.

At many of the larger offices, and at all London telephone exchanges, a motor-driven dry-air plant is permanently installed. A view of such a plant is shown in Fig. 464, from which it will be observed that the air is passed through a container and finally through the cylinders on its way to the cables. The duplex compressor or pump is driven by

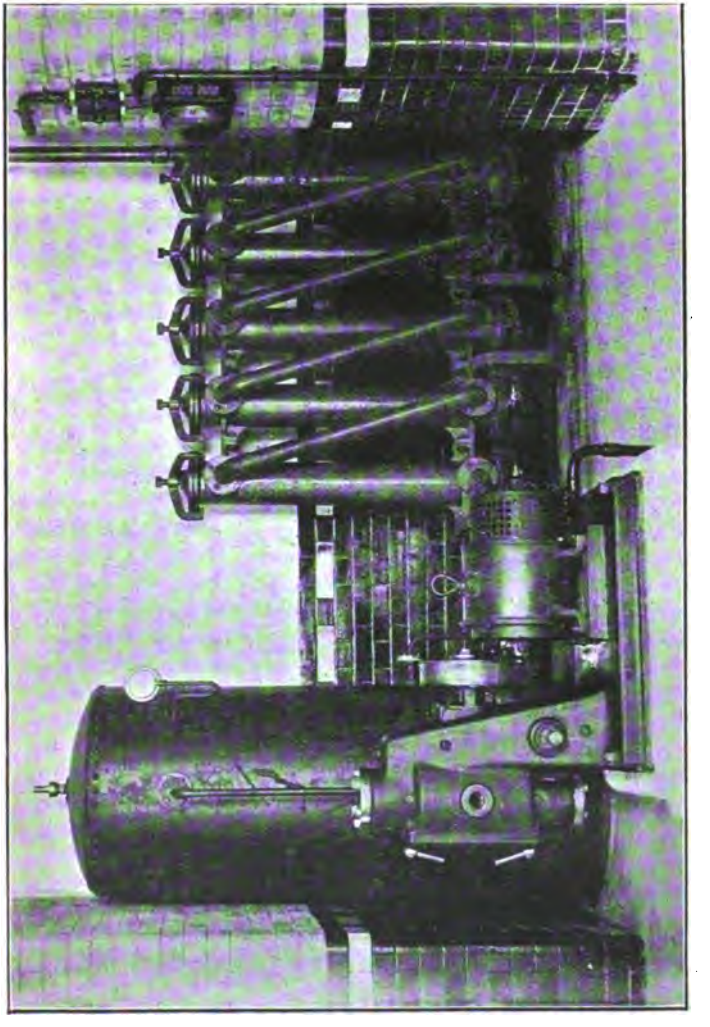


FIG. 464.—General view of a motor-driven dry-air plant.

a 2 H.P. motor, mounted upon the bed plate. Escape or safety valves set to blow at 20 lbs. are provided both upon the motor and the container, which latter also carries a pressure gauge. The desiccator consists of five cylinders within each of which is placed a muslin bag containing the calcium chloride. In large telephone exchanges the dry-air supply is permanently connected to every cable, a tap being interposed upon the branch pipe.

Electrical Tests during Construction.

The cable is subjected to a series of electrical tests after each joint has been completed, the objects gained being to prove (1) that the insulation of the wires is maintained, (2) that contacts and disconnections do not exist, and (3) that the wires have been correctly jointed; for example, with a twin wire cable it is essential to prove that the two wires of each twisted pair are jointed through to the two wires of a twisted pair, *i.e.* to ensure the two wires forming a pair are twisted together throughout the length of the cable.

These tests may be readily made if the cable is first jointed to the cable connection-box at the office from which it proceeds. Lengths of india-rubber-covered wire are soldered to "insulated pin-connectors" which serve to connect the leads to the pins in the cable connection-box. The other ends of these leads are passed through holes in a board and the ends bared. By arranging the wires which may be tested together in rows and by furnishing a terminal for each row the actual tests are greatly facilitated. The bared ends of the leads are connected with very fine tinned copper wire (No. 30) in rows to the terminals which are normally earthed. To test any particular group the fine wire is taken from the terminal and connected to the testing lead whilst leaving the remaining wires to earth. It should be pointed out that the board should be perfectly dry and that there should be no leakage upon the testing leads. Where such leakages exist they will usually be found to occur at the surfaces of the bared ends of the various leads.

When the first joint has been made, the lead covering at the end of the cable is removed and the wires carefully separated, and, if necessary, all traces of moisture removed

by means of braziers. The insulation test is then made as indicated above. The cable is tested as each joint is completed, and any defect is therefore discovered with promptitude and certainty. The minimum insulation resistance during construction may be as high as 5000 megohms per mile—a value which is only attained when scrupulous care as to dryness is observed.

The test for continuity and correct jointing is usually made by exchanging "beats" upon detectors, thereby ensuring that the wires have been correctly paired, and also that pairs have not been crossed between the various layers. It is, of course, quite possible to cross a pair in, say, the outside with one in the next layer, but at the subsequent joint these two pairs may be at opposite sides of the cable.

Of course, a trembler bell might be used instead of a detector, so substituting an audible for a visual signal.

With short lengths of cables containing a very large number of wires the systematic tests described are scarcely practicable owing to the time occupied. It will, therefore, usually suffice to make a single set of tests upon completion of the work, or, if desired, the joints may be made and tested in sets of three. The following procedure is, however, to be preferred: The wires are looped in pairs at the cable connection-box or test-frame, and the jointer may then prove his own pairs or the work may be done by a foreman. The insulation test is taken after each set of three consecutive joints has been made. A fairly reliable rough test may be made by occasionally testing a few of the wires in the outer layer.

It is generally of considerable advantage to provide a means of communication with the jointer, and this is done by furnishing him with a portable telephone for connection to one of the pairs.

The maintenance testing of a working cable is accomplished by taking out one pair of wires upon the outside layer and specially connecting them with rubber-covered wires, so that there is no leakage upon the leads. The periodical tests of these wires are usually a sufficient index to the insulation of the cable. It would scarcely be practicable to make the series of tests already described without causing serious delay to the traffic, or without a considerable

amount of Sunday work, both of which courses are equally objectionable.

Cable Connection Boxes.

A cable connection box fitted to receive the two sides of a 54 wire cable such as is used in pillar test boxes, is illustrated in Figs. 465, 466 and 467. It consists of a cast-iron box with two lids divided by a central diaphragm, through which pins, insulated with ebonite, are fixed, so as to be perfectly airtight, whilst affording electrical connections between the two compartments. The two cables are passed through the gun-metal linings and plumbers' wiped joints are made between the sheathings and the linings. The lead is stripped off the lengths of cable within the box, and the wires are soldered to the connection pins. When this has been done the wires are thoroughly dried by means of braziers, and the lid fixed by nuts and bolts, the design of the lid and the linings being such as to secure a perfectly air-tight joint. The two cables are connected by short lengths of insulated wire soldered between the pins of each cable upon the other side of the diaphragm. This compartment is then closed by a similar lid to that used upon the cable side. In order to make tests or effect crosses the cable side of the box need not be interfered with, since the short lengths of insulated wire upon the other, or cross-connection

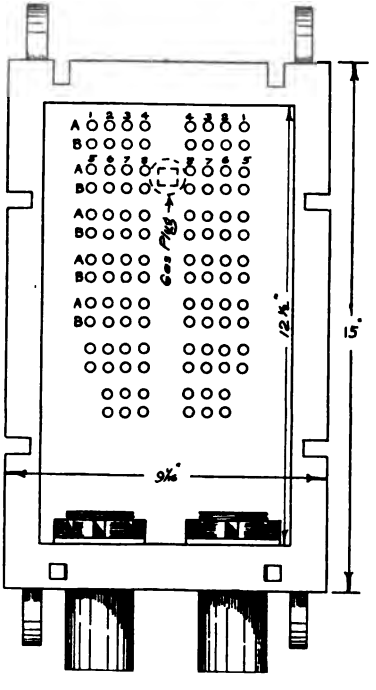


Fig. 465.—Back view of cable connection box with lid removed.

side of the diaphragm may be manipulated as required. A $\frac{3}{4}''$ gas plug is added, so that dry air apparatus may be con-

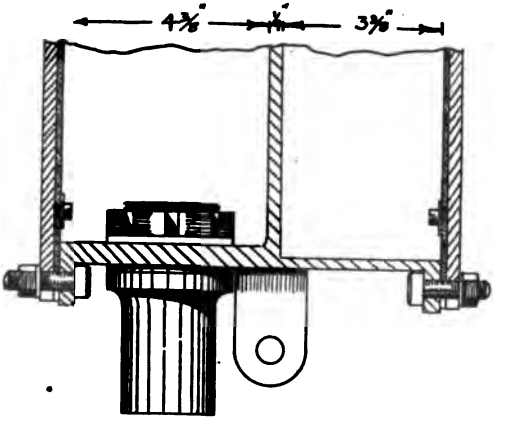


FIG. 466.—A vertical section of the box from front to back.

nected or an escape provided when it is only necessary to pump through one cable from a distant point. The latest pattern of box is arranged for attachment to a wall by means of Lewis bolts; thus making it possible to readily remove either lid. The older pattern is, however, still used in pillar test boxes.

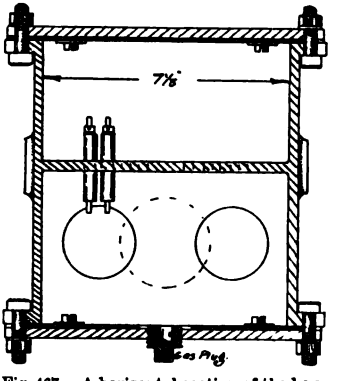


Fig 467.—A horizontal section of the box.

It may now be explained that the wires in an ordinary twin, quadruple pair, or multiple pair air-space cable are numbered in pairs, and that the two wires of each pair are distinguished as the *A* and *B* lines—a convention which owes its origin to telephonic requirements. The wires of screened single-conductor cables are, however, numbered individually.

Each cable is terminated with a single solid plug, having a number of 2-wire lead cables equal to the number of pairs in the cable. The joints between the single solids are then made in the ordinary way, and a small lead sleeve soldered over each joint.

2. It is required to provide access at a particular box to every pair of wires in a 27-pair cable.

In this case a double solid plug, consisting of a length of 27 2-pair cables embedded in two lead castings, is required. The cable is connected upon each side and the joints completed as described in the case of the single solid joint. As each wire is numbered by means of a lead label, the requirements laid down have been fully met (see Fig. 469).

It will be obvious that any wire may be looped into an

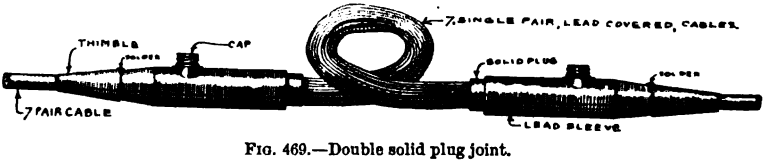


FIG. 469.—Double solid plug joint.

office for intermediate working, or that a wire or wires may be led into the office to connect up its instruments.

3. A cable consists of n_1 pairs of wires, and n_2 single screened conductors for telegraph circuits. It is required to lead off certain of the screened conductors, provide access to the rest, but to leave the telephone wires intact at the point in question.

The double solid plug would, in this case, consist of an n_1 pair cable in the centre, and n_2 single lead covered wires ranged around it in the plugs. Any of the telegraph wires may therefore be cut and led off, or looped in as may be required.

RENEWAL OF G.P. WITH DRY CORE CABLES.

The substitution of a lead covered cable for G.P. cables may be effected quite easily in those cases in which there is sufficient room for the lead cable to be pulled in over the G.P. wires. This course should, however, only be

adopted where there is ample margin for the reception of both cables. Another method is to employ an interruption cable slung upon the lamp-posts or upon short poles standing in barrels along the route. The circuits are diverted through the temporary cable, the G.P.'s withdrawn, and the lead cable pulled in and jointed, the end being connected to rubber-covered wires, and the joint enclosed within a sleeve, filled either with insulation compound or with paraffin wax. This is colloquially termed "tail-ending the cable." In this way the lead cable may be substituted in sections of from 400 to 800 yards.

Yet another method has been adopted, but this is, in principle, similar to the system of renewing old by new G.P. wires. A second or subsidiary small drum is mounted upon the same axle as the cable drum. The inner end of the cable is jointed to lengths of india-rubber-covered wires, whilst the outer end is tailed off, and a special clip which grips the lead sheathing without straining the tailed joint is affixed. The cable is then cut in at the box from which it enters the pipe and the lead cable pulled in, whilst the length of G.P. is simultaneously pulled out. The object of the subsidiary drum is to preserve the connection with the rotating cable drum, and a certain length of rubber wire is necessarily wound on to the small drum during the operation of pulling in. It is therefore necessary to provide sufficient slack wire to allow for this—usually about one-third of the length of cable pulled in suffices.

Renewal of Dry Core Cables.

The renewal of dry core cables may best be accomplished by means of a temporary cable and tail-ending, but it may also be effected by a modification of the subsidiary drum method. Where a cable having a larger number of wires is to be substituted it may be possible to adopt the method used with G.P. wires, but the junction between the new and the old cable must be carefully protected from moisture, and from longitudinal stress whilst pulling in.

Surveying.

As regards surveying for a new underground route, but little which is not fairly obvious can be said. The type of

paving is, of course, a vital factor in the cost of the work, and where it is possible to make a choice the cheaper proposal is selected. The obstructions likely to be met with may be ascertained by observation and by direct inquiry. In the first category come projecting cellars, electric light mains (from the position of the boxes), etc. Inquiries made from the Electricity Supply authorities, from the Gas and Water Companies, usually suffice for estimation of the obstructions.

Where the choice of routes lies between busy and comparatively unfrequented thoroughfares, the latter are chosen on account of the superior facilities which they offer for the execution of the work and its subsequent maintenance. At the same time, tortuous routes and frequent road crossings should be avoided, but there is little in these considerations which is not of a very obvious character.

The pipes should where possible be laid in straight lines between consecutive boxes in preference to following the lines of the kerb. Electric light mains should be given as wide a berth as possible on account of possible faults leading to the formation of an arc with the Department's pipes.

As in the construction of aërial lines, so with underground work, can economy be effected by carefully considering the laying out of the stores and general organization of the work.

Faults.

A total disconnection in a cable may be localized by measuring the capacity of the wire from each end of the cable, whereas a partial disconnection or a defective joint has to be located by opening the various joints *en route*.

The positions of an earth or contact fault may be localized as described on pages 644 to 647.

The breakdown of the whole route, due to the entrance of moisture, is usually due to a defective wiped joint, but with the dry-air test which is now employed this occurrence is comparatively rare. When the four wires upon the outer layer are periodically tested, there is frequently ample warning that a defect exists, and, by applying the dry-air plant, its position may readily be located.

It is sometimes necessary to cut out a short length of

saturated cable and substitute a new piece, but the method of accomplishing this is so obvious as to need no comment.

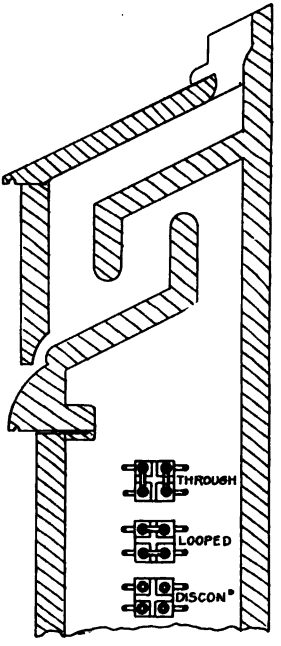


FIG. 470.—Portion of a pole test box, front elevation.

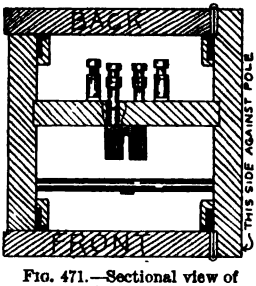


FIG. 471.—Sectional view of pole test box.

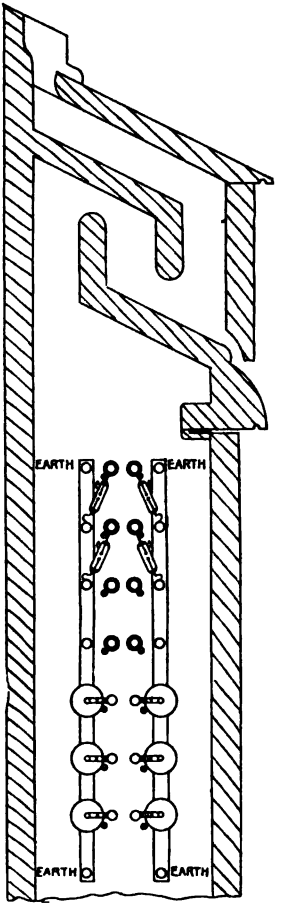


FIG. 472.—Back elevation of a pole test box.

POLE TEST BOXES.

It is often necessary to provide testing facilities, *i.e.*

facilities for looping, crossing, disconnecting, or earthing the wires, at points which are remote from any office where an ordinary test box can be provided. Such points may mark the division between Post Office and Railway Company's maintenance. In these cases, test boxes affixed to the poles are employed, but the design is, of course, widely different from that used indoors. At the junction between an open and underground line, pole test boxes are provided, but, in this case, they also serve to carry the fuses and lightning protectors needed to ensure the safety of the covered wires.

When testing facilities only are needed the pole test box is of the "D" type, but when protectors are also required the "E" type is fitted. As these two types are of somewhat similar design it will be convenient to describe the "E" box, and then to indicate the simplifications which are effected as a result of the absence of protective devices.

Each wire passing through the box is represented by two brass test holes, mounted upon an ebonite block, and connected together by means of a U-link. Since the boxes are also used for telephone circuits, and the test holes are mounted in sets of four, and boxes capable of accommodating from 8 to 80 wires by gradations of 8 have been designed. The term wire is, in this connection, used to denote one wire in and out, *i.e.* an 8-wire box would provide for passing 8 wires through the box, and would therefore contain two sets of four test holes. The line wires are soldered to the tags (see Fig. 470) connected to the various test holes. The upper pair of each set of A test holes is continued through the dividing board, and small binding screws are fitted into the tubular extremities. Fig. 472 shows the way in which either vacuum or "C" protectors may be fixed between the pillars and the earth bars. As previously stated, C protectors are fitted wherever possible, and it is only when the damp nature of the locality absolutely prohibits their use that the vacuum type is employed. It will not be out of place to again emphasize the importance of securing a good earth connection by connecting the stranded wire to the iron pipes and by sinking a special earth plate. A spiral in the wire is made as close to the upper test holes upon the underground side as possible, whilst the open side is taken quite straight to the

lower, since a spiral in this case would prove a source of absolute danger. The spiral consists of about 10 turns of wire with a diameter of $\frac{1}{4}$ to $\frac{3}{8}$-inch.

Fuses are inserted by means of "fuse U-links" which take the place of links of the ordinary type. These links, one of which is shown in Fig. 473, consist of a block of ebonite to which two peg-like projections and the fuse clips are secured. The fuses themselves are of the ordinary glass tube pattern illustrated in Fig. 324.

The design of the roof prevents water from passing into the interior of the box through the wooden casing used to carry the wires to the arms. In small boxes the wires enter and leave the box at the bottom, but with large boxes this is frequently impracticable.

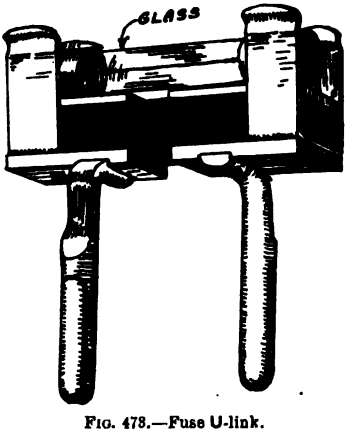


FIG. 473.—Fuse U-link.

The doors are hinged and bed against rubber cushions fixed round the edges of the box. Each door is closed by screws, so shaped that they cannot be removed from the door, and a special forked screwdriver is provided for turning them. This device renders it extremely unlikely that any mischievously disposed person could open the box, provides a secure and tight fit between the lids and the box, and precludes the possibility of the loss of the screws.

When testing facilities only are needed, *i. e.* where the route upon both sides of the pole is an open one, the box opens upon the front only, instead of upon both sides. This simplification is possible because protectors are unnecessary, access to the back of the board upon which the test holes are fixed not being required.

The arrangements required at the junction of an underground and open route are conventionally indicated in Fig. 474. The underground route commences at the cable connection box in the underground chamber, and

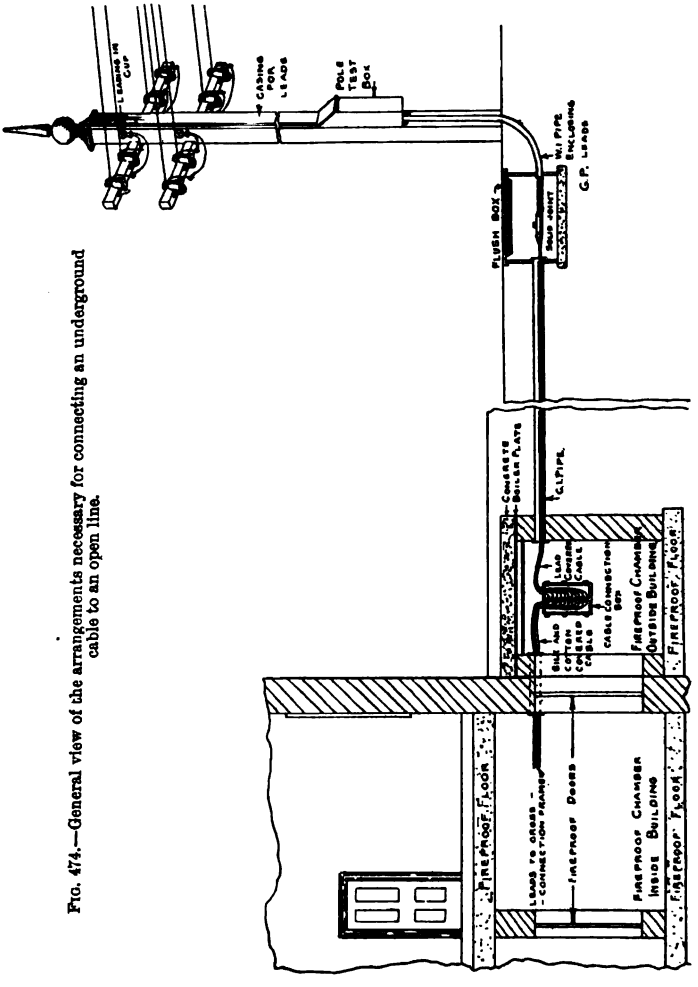


FIG. 474.—General view of the arrangements necessary for connecting an underground cable to an open line.

terminates in a solid plug fixed upon the side of a suitable flush box at the base of the terminal pole. From this plug the G.P. leads pass into the pole test box by means of a cast-iron bend and pipe. The leads upwards are also of G.P., and emerge from the wooden casing through leading-in cups whence they join the open wires.

The neatest method of providing the casing consists in screwing two 1″ plinths flush with each edge of the pole, and it is to this that the cover is attached. The leading-in cups are placed upon the side of the pole and $\frac{1}{2}$″ holes are made connecting them to the casing.

The leading-in cup consists of a curved porcelain tube protected by an iron cover provided with flanges screwed to the casing. The device affords mechanical protection to the leads just in the same way that the ebonite bends protect the wires upon iron poles. It may be added that, as creosote has a most deleterious effect upon gutta-percha, it is necessary to prevent the leads from coming into contact with creosoted poles.

APPENDIX.

SECTION A.

THE MOLECULAR THEORY OF MAGNETISM.

THE well-known experimental fact that a magnet may be broken into any number of pieces and yet each piece still be found to be a perfect magnet early suggested that magnetic properties were of molecular* origin. From this point commenced the evolution of molecular theory of magnetism which has reached its present development by the labours of Prof. Ewing. This theory, which so closely and accurately fits the known facts of magnetism, states that every molecule of a magnetic substance is always a magnet, perfect and complete in itself, and that magnetization is due to the molecular magnets being more or less completely faced round, in opposition to their mutual attractions, so that they tend to act in the same direction. In the unmagnetized condition the molecules are in positions in which their mutual attractions are satisfied. Consideration will show that when this is the case the total effect of the collection of molecular magnets will be *nil*, since half the North poles will be pointing in one direction whilst the rest are acting in the opposite direction. The intensity of the magnetization has a definite limit known as the point of saturation, and as it is desirable that a clear conception of the physical meaning of this state should be realized, a simple illustration of the two conditions of a piece of unmagnetized iron and of the same saturated will be shown here—

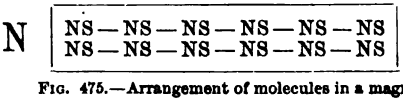


FIG. 475.—Arrangement of molecules in a magnet.

* For definition of molecule, etc., see p. 809.

Each pair of small letters *NS* represents a molecule of a magnetic substance. Twelve molecules only have been shown, whereas the smallest magnet used in practice consists of billions. The twelve molecules all face in the same direction, viz. with their North poles to the left, and the effect of their combined action is to produce North polarity on the left and South on the right as indicated by the pair of large letters *N* and *S*. Since the magnets are all acting in exactly the same direction it will be obvious that the effect produced will be the maximum possible, and this condition is termed saturation.

The unmagnetized condition of the iron may be represented thus:—

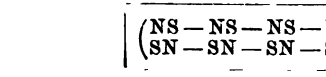


FIG. 476.—Arrangement of molecules in a piece of unmagnetized iron.

Here it will be noticed that half the magnets point one way whilst the remainder act in the opposite direction, and the net result is therefore *nil*. It is most important to note that in this condition the attraction of each magnet is satisfied by that of its neighbour. The lower six magnets have turned through 180° from their positions in Fig. 475.

It is important to realize that the prime cause of this rotation is the satisfaction of the mutual attractions of the molecular magnets. Imagine, therefore, that the magnetizing force is withdrawn from the piece of iron shown in Fig. 475. The molecules are perfectly free to turn round, but their distances from each other are fixed. If the upper and lower molecules on the left were absolutely parallel the repulsion of the two Norths would balance that between the two Souths, and their positions would remain unchanged. This balance would probably be far finer than that necessary to balance a billiard ball upon the point of a needle. In other words the position would be an unstable one, liable to be upset by the most minute vibration. The result would therefore be that the attraction between the poles of opposite sign would produce a rotation of one of the molecules. This will be rendered more obvious by considering the distance between the molecular magnets greater than their length.

In the case of steel the molecules appear to be in some way jammed, and are very difficult to turn round, but when this has been done the mutual attractions are not strong enough to produce de-magnetization. When, therefore, a piece of steel is magnetized it remains magnetic after the removal of the magnetizing force, and is then termed a permanent magnet in contradistinction to iron, which, on account of its molecular inter-attractions, returns to the non-magnetic condition immediately the magnetizing force is withdrawn.

Having considered the two extreme states of non-magnetization and saturation it is now desirable to investigate the conditions which lie between them. In an actual magnet it is highly improbable that the arrangements of the molecules are of the remarkably simple character shown in Figs. 475 and 476. The molecules are arranged in groups of varying number and complex chains, and groups which are, from a magnetic point of view, self-contained, exist in such a manner that the attractions of each member of a group or chain are satisfied by those of the others.

If a very small directive magnetic field is applied to the piece of unmagnetized iron the various molecules are slightly deflected from the positions which they occupy. This small deflection of the various members of the groups disturbs the balance of poles and a magnetic effect due to the iron is observable. By increasing the value of the directive field the molecular deflections increase, thus definitely increasing the magnetic effect due to the iron. At this stage the magnetic effect due to the iron itself is very roughly proportional to the value of the directive field. A point is, however, soon reached where a small increase in the value of the directive field produces very large increases in the magnetic effect due to the iron. At this point the deflections have become so great that the chains and groups become unstable and finally break up altogether. The great changes which ensue naturally entail a largely increased magnetic moment. These changes increase in magnitude with the increase of the magnetic field applied until a point is reached where the molecules have reached a stable position. Further increases of directive force now produce smaller and smaller increases of moment until a point is reached where no appreciable increase of moment

can be obtained. This is the point of saturation, and corresponds to the extreme condition shown in Fig. 475.

Since, however, the position which the molecules take up is the resultant of two opposing forces, viz. the directive force and the inter-attractions of the various members of the numerous groups, the molecules can never all of them wholly act in the same direction as the directive force.

The magnetization of a piece of iron may be divided into three definite stages. There is the first stage in which the molecules retain their groupings, but each member is deflected. In the second stage the deflections are greatly increased, and the groups and chains are unstable. In the third stage the increases in moment are due to increased deflections of the molecules.

During the first stage of the magnetization the removal of the directive force will at once enable the molecules to resume precisely their original positions. This demonstrates the experimental fact that iron which has been but weakly magnetized exhibits little or no residual magnetism. Turning now to the second stage where the groupings are unstable, and where large changes have occurred, it is not surprising to find that the withdrawal of the magnetizing force does not cause each molecule to resume exactly its former position. New groupings are formed and the molecules satisfy each other's attractions in the most unsymmetrical fashion. The result is that there is left a distinct magnetic moment due to the molecules. The residual magnetism observed is thus accounted for. That which has been said of the second applies equally to the third stage, and it is a well-known experimental fact that considerable residual magnetism is observed when the magnetizing force is withdrawn.

The results obtained from the above considerations clearly show that the amount of magnetism which a piece of iron manifests depends upon the value of the magnetizing force. At first the effect increases comparatively slowly to a certain point where small changes in magnetizing force produce large changes in the resulting magnetization. Finally the point of saturation appears. In the first stage there is little residual magnetism in comparison with the second and third stages.

It should be stated that Ewing's theory was based upon

the observation of the behaviour of a flock of freely pivoted compass needles placed close together with a large circular coil of wire at either end of the group. The current through these coils could be varied to any required extent and a directive magnetic field of any particular value caused to act upon the group of needles. Their behaviour entirely corresponds with the statements made in the description of the behaviour of the molecules of iron. Indeed, the quantitative values of magnetic effect due to the needles themselves show a remarkable correspondence with the values obtained in practice from a piece of iron. The theory is supported by innumerable facts, and its accuracy can scarcely be questioned.

SECTION B.

NOTES ON CHEMISTRY.

A LUMP of sugar may be pounded with a hammer until the particles are very small, and by using a mortar and pestle their size can be still further reduced. If, however, these particles are examined by means of a microscope, or even by an ordinary lens, it will be found that the particles have still some size, and evidently could be made yet smaller. If the sugar is dissolved in some warm water the particles will become so small as to be invisible, but we know by the taste that the sugar is there. We may dilute it largely and still recognize the sugar, which is evidently distributed equally throughout the liquid. The question now arises as to whether the sugar is capable of unlimited division. Experiments prove that it is not, but that ultimately a particle which will no longer split up and yet remain sugar will be arrived at.

This is called a *molecule*, and is the smallest particle which can exist free. Sugar is known to consist of carbon and the elements of water, *i. e.* hydrogen and oxygen, and if a little strong sulphuric acid be added to the sugar solution the acid will combine with the water, black carbon will be liberated, and the vessel will become very hot. If the sugar is dissolved in some warm water in a tall glass, and the strong sulphuric acid poured slowly in, the carbon will rise and flow out of the glass in a remarkable manner. It may be remarked in passing that this heat is caused by the chemical action, and is always given off during chemical union. Now it is clear that the molecule has separated into still smaller particles of substances quite distinct from sugar. These particles are called *atoms*, and every molecule is so built up. The carbon produced has

not yet been decomposed, and is therefore called an *element*. It is evident that compounds are made up of elements, but it is also as certain that elementary atoms do not exist alone but in groups or molecules, generally of two atoms, but in one or two cases of one, two, three, four or even six atoms. An *atom* may therefore be defined as the smallest particle of matter that can enter into combination. An atom of hydrogen is represented by H, but in the free state as a molecule as H_2. An atom of oxygen is represented by O, a molecule by O_2, and a molecule of ozone by O_3, showing that in this gas three atoms are condensed into the same space as two of ordinary oxygen.

In order to avoid writing the names of each of the elements composing a compound a system of chemical symbols is used, thus: Hydrogen is represented by H; Sulphur, S; Copper, Cu; Carbon, C; Oxygen, O; Manganese, Mn; Zinc, Zn; Mercury, Hg; Chlorine, Cl; Potassium, K; Chromium, Cr; Nitrogen, N; Lead, Pb; Sodium, Na.

A number placed after a symbol indicates the number of atoms which is to be considered. For instance, a molecule of sulphuric acid consists of two atoms of hydrogen, one of sulphur, and four of oxygen. In order to write this quickly each element has been given a distinctive symbol, and to indicate the number of atoms in each element in the compound a figure stating the number is placed after each element. Where, however, there is only one atom the figure "1" is understood and is not written. Sulphuric acid is therefore H_2SO_4. In order to express more than one molecule of a substance a large figure is placed before the compound thus—$2NH_4Cl$. This means two molecules of NH_4Cl, or two atoms of nitrogen, eight of hydrogen, and two of chlorine. $2H_2$ means two molecules of hydrogen, each of which consists of two atoms, *i. e.* four in all. $4Cr_2(SO_4)_3$ is the symbol for four molecules of chromium sulphate, each of which consists of two atoms of chromium, three of sulphur and twelve of oxygen.

Chemical compounds are known by the thousand, but there are also groups of elements which have no independent existence, but which can take part in chemical reactions and be transferred from one compound to another. These groups are called *radicles*. An atom of hydrogen H

or oxygen O are elementary radicles. SO_4, NO_3, HO are compound radicles. Radicles are also divided into metallic as Na, Zn, NH_4 and acid as Cl, SO_4, NO_3.

It is evident that they exist free for a very short interval, in chemical reaction, before they re-unite to form fresh molecules. In this condition they are said to be *nascent*, and their chemical activity is very great.

Compounds are formed by the union of these radicles in almost every conceivable way, but the great majority belong to the three following groups :—

1. *Acids* which are extremely active chemical compounds and are formed by the union of hydrogen, H, with an acid radicle, as :—

   H_2SO_4 Sulphuric Acid,
   HNO_3 Nitric Acid,
   HCl Hydrochloric Acid.

2. *Bases.* Hydrates or hydroxides are formed by the union of the radicle hydroxyl HO with a metallic radicle, as :—

   Potassium hydrate KHO.
   Ammonium hydrate NH_4HO.

3. *Salts* are formed by the union of a metallic and an acid radicle :—

   Zn SO_4 Zinc Sulphate.
   NH_4 Cl Ammonium Chloride.

The metals are often called positive elements and the non-metals negative, or still better a list of the elements can be made, the highest being the typical negative element oxygen, and at the bottom the typical positive element potassium. In this list each metal is negative to those below and positive to all above it. Also the further they are apart the more intense the chemical affinity. The radicles may also be classified as positive and negative, thus SO_4 is negative because it is combined with the positive H, and the definition will become :—

An *acid* formed of hydrogen and a negative radicle,
A *base* formed of hydroxyl (HO) and a positive radicle, and
A *salt* formed of a negative and a positive radicle.

Now to split up a compound requires energy, and when separated they possess potential energy. When the elements re-unite the energy is reproduced, and may exhibit itself in the form of heat, light, electricity, etc. Thus the sun for ages decomposed the carbonic acid gas in the coal forests, and with the carbon the plants were built up. This energy, after lying dormant for millions of years, is now utilized by us in the form of heat, really the original heat poured out by the sun ages ago.

Thus we see man can neither create nor destroy energy, and it is equally certain that he cannot create or destroy matter. All he can do is to change its distribution, and in so doing change its external appearance. Hence, in any chemical equation, every atom taking part in the reaction must be accounted for, *i. e.* if you have ten atoms on one side of your equation you must have ten on the other. The *quantities* of each element must be the *same*, but their *distribution* may be entirely different.

If a piece of pure zinc is placed in dilute acid, as for instance, sulphuric acid, no action takes place. If now, a piece of carbon, platinum or copper is also placed in the solution there is still no action. Lastly, if while they are in the liquids the elements are connected outside either by touching them together or joining them by a wire, the zinc immediately dissolves, while hydrogen gas is given off from the surface of the copper. At the same time the wire is very different to what it was in its normal state. It will deflect a magnetic needle as in the telegraph, make soft iron into a magnet, and produce other electrical phenomena according to the strength of the action. The energy of the chemical action exhibits itself as electricity, and a current of electricity is said to flow from the copper to the zinc outside, and from the zinc to copper inside, thus completing the circuit.

Several theories have been put forward to account for the current in the wire, but there is nothing certain known of what takes place in the wire when the connection is made. It is probable that it is due to ether waves in or around the wire. The copper plate is the positive pole and the zinc the negative, which can be remembered thus :—

CoPper Positive,
ZiNc Negative.

The vessel is called a cell, and a number of cells put together and joined up is called a battery. The action in the cell may be represented thus :—

Before the poles are connected.					After connection.		
Zn	+	H_2SO_4	=	$ZnSO_4$	+	H_2
One molecule of zinc	and	One molecule of sulphuric acid	form	One molecule of zinc sulphate	and	One molecule of hydrogen.

The copper plate is not acted upon by the chemical constituents of the cell, and is therefore omitted from the equation.

The reaction depicted by the above symbols represents a molecule of zinc acted on by a molecule of sulphuric acid, the result being that the zinc and the two atoms of hydrogen of the sulphuric acid change places, when we have zinc sulphate with hydrogen free instead of hydrogen sulphate (another name for sulphuric acid) and zinc free.

The solution of zinc sulphate at once leaves the zinc, and being heavier than water slowly sinks, so that fresh surfaces of zinc are continually being exposed to the action of the acid. The current will cease when all the zinc has been consumed, *i. e.* reduced to zinc sulphate. But in the case of the copper the hydrogen collects in a thin layer and clings to the surface. This is called polarization, and of course interferes seriously with the current. The remedy is to introduce another liquid which will unite with the hydrogen and remove it continuously. In the description of the various cells these will be mentioned as they occur. In the instance we have used for our illustration, that is the two elements zinc and copper and sulphuric acid, the sulphuric acid is called the exciting fluid, and the liquid used to remove the hydrogen is called the depolarizing fluid, and may be a solution of copper sulphate forming sulphuric acid and metallic copper. The latter forms a layer on the original copper element and therefore the action is not impeded.

According to the most recent investigations, when sulphuric acid dissolves in water part of it at once separates into the radicles H_2 and SO_4, or *ions*,* as they were first

* Strictly speaking, H is an ion but not H_2.

termed by Faraday. These are in equilibrium with themselves, and the copper and zinc, but directly the connection is made and there is a means of escape for the energy, the zinc attracts the SO_4 and the hydrogen goes to copper. A fresh portion of H_2SO_4 decomposes into ions, and so the action goes on continuously.

Similarly when sodium chloride, NaCl, is dissolved in water it will immediately split up into the *ions* Na and Cl. Now, if a current of electricity is sent through this solution the Na is attracted by one pole and is set free, forming NaHO with the water, and the Cl is attracted by the other and escapes as gas. Some more NaCl decomposes, and the action goes on until all the salt is decomposed.

Substances like sugar ($C_{12}H_{22}O_{11}$) with a very large number of atoms are not decomposed by electrolysis and consequently do not split up into *ions*.

What has been said about the atom is based on Dalton's Atomic Theory, which assumes that the atom is the ultimate form of matter, and is indivisible and indestructible. It must, however, be mentioned that the researches of the last few years, especially the discovery of Radium, have led to the conclusion that the atom itself is composed of thousands of still smaller particles in rapid motion. These have been called *electrons*. Also that the new element Radium with an atomic weight of 250 is capable of breaking into Helium whose atomic weight is 2.

Additional Definitions.

An *electrolyte* is a liquid which undergoes *electrolysis*, *i. e.* chemical changes, when traversed by a current.

The *electrodes* are the conductors in contact with an electrolyte by means of which the current enters and leaves the liquid.

The *kathode* is the electrode by which the current leaves the electrolyte and the *anode* that by which it enters.

The *anion* and *kation* are the elements (or groups of elements) liberated at the anode and kathode respectively.

In the simple voltaic cell considered zinc, is the anode. copper the kathode, and hydrogen the kation.

SECTION C.

SUPERIMPOSING.

THERE are several systems by which a telephone circuit may be used for simultaneous telegraph and telephone work. Of these, the van Rysselberghe system, which is extensively used in Belgium, enables two telegraph circuits to be obtained from a metallic telephone circuit.

The arrangement of such a circuit is indicated in Fig. 477, the telegraph apparatus at *F* and *G* being precisely as that at *C* and *D*.

The principle of the system consists in slowing down the rate at which the telegraph currents rise and fall to such an extent that no audible effect is produced upon the telephone receivers, whilst the telephone speaking currents are, of course, so small as to be quite incapable of affecting the telegraph apparatus. In order to separate the two telegraph circuits four condensers, each $\frac{1}{2}$ m.f. capacity, are inserted in the lines. Since the speaking telephonic currents are of a rapidly alternating character, the interposition of these condensers does not appreciably affect the talking between the telephones at *A* and *B*. The telegraph circuits are all arranged in precisely the same manner (Fig. 477). An inductive resistance termed a "graduator" is inserted between the centre of the key and the line, whilst a second and similar coil is joined between the battery and front stop of the key, a 2 m.f. condenser being connected between the centre of the key and earth. When the key is depressed the battery commences to charge the condenser and the difference of potential between the centre of the key and earth rises slowly, while the graduator in the line circuit tends to still further reduce the rate at which the current increases. It will therefore be seen that the current rises

very slowly and that the portion which passes through the nearer condenser, telephone *A*, condenser, and telegraph apparatus *F* upon the other line whilst the current is rising is far too small to affect the telegraph apparatus, and since it rises so slowly the telephone is likewise unaffected. Consideration therefore shows that the two telegraph circuits may be worked simultaneously upon the metallic loop without interference with telephonic speech or with each other.

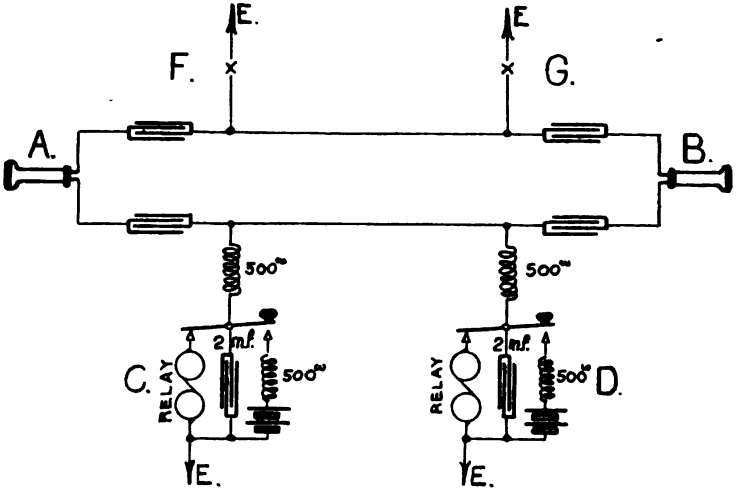


FIG. 477.—Van Rysselberghe system of simultaneous telegraph and telephone working; the apparatus at *F* and *G* is precisely similar to that at *C* and *D*.

The only point to be remarked is that, for calling purposes upon the telephone circuit, it is necessary to adopt a special device which will not affect the telegraph circuits as would the use of an ordinary generator. This is accomplished by the low frequency current from a small induction coil acting upon an extremely sensitive form of relay at the distant end.*

The systems used in this country enable one telegraph to be worked over a metallic telephone circuit but without, in any way, affecting the arrangement of the telegraph

* See Chapter IV, "Telegraph Switch System," by T. F. Purves.

apparatus or the system of ringing over the telephone loop. If the circuit is in perfect condition there will be absolutely no effect upon the telephones when the telegraph stations are working. There are two methods of arranging for the superimposing, the one by the aid of transformers and the other by means of bridging coils.

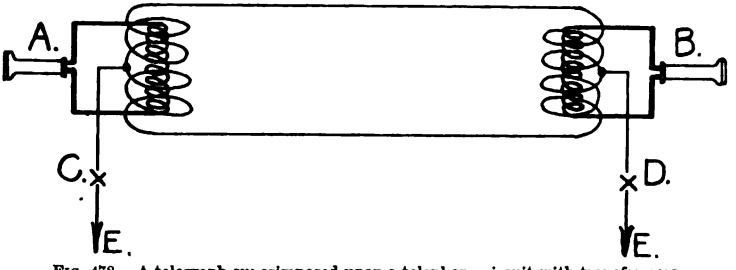


FIG. 478.—A telegraph superimposed upon a telephone circuit with transformers.

A telephone circuit, conventionally depicted in Fig. 478, has a telegraph circuit superimposed upon it by means of transformers. The transformer (Fig. 479) is an induction coil of special design and has a closed magnetic circuit formed by fine iron wires. The speaking currents from *A* pass through the primary winding and induce corresponding currents in the secondary, which in passing through the secondary at *B* induce currents in the primary, so actuating the telephone at *B*. The speaking in the reverse direction (*i.e.* *B* to *A*) is effected similarly. The central points of the two secondaries are connected to telegraph sets joined up in the ordinary manner. The telegraph currents from *C* divide equally through the two sides of the secondary, and as these two halves of the windings oppose each other the core of the transformer is not magnetized and therefore no E.M.F. is induced in the primary. The two halves of the total current pass along both lines in parallel, re-unite at the centre of the transformer at *B*, and pass through the apparatus at *D*

FIG. 479.—A transformer.

to earth. It will therefore be seen that there is no interference between the telephone and telegraph circuits.

The two lines must, however, be equal in conductor resistance, in insulation resistance, and in static capacity.

This system has been used to combine a single wire telephone circuit and a telegraph circuit upon a main

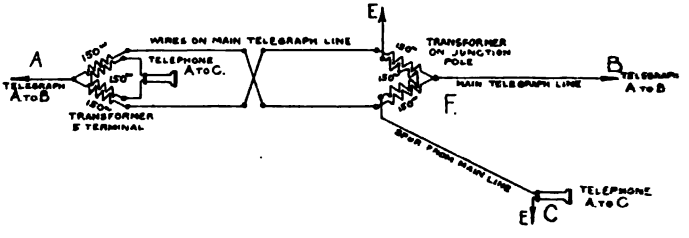


FIG. 480.—A single wire telephone circuit combined with a telegraph wire to form a metallic telephone circuit upon a main telegraph line.

line route so as to cut off the inductive disturbances upon the telephone circuit. In country districts where there are neither electric tramways nor other telegraph and telephone circuits in the vicinity a single wire circuit is

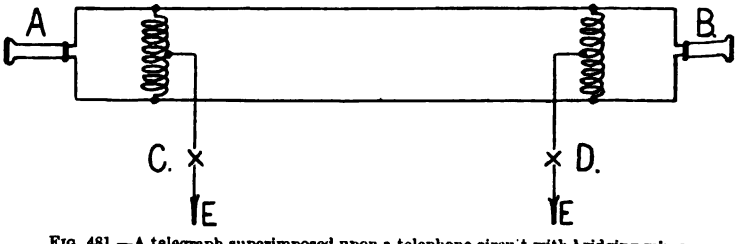


FIG. 481.—A telegraph superimposed upon a telephone circuit with bridging wires.

quite adequate for the transmission of messages over a short distance.

An example of such a circuit is given in Fig. 480, where the *A*—*B* telegraph circuit allied with a section of the *A*—*C* single wire telephone circuit provides a metallic telephone circuit between *A* and *F* with the telegraph superimposed upon it. There is therefore only the inductive disturbance and earth current effects between *C*

and *F* upon the line, and in many cases this is quite of an insignificant character. It is, however, necessary to cross the two wires so as to eliminate inductive disturbances from the other circuits working upon the main line between *A* and *F*.

A telephone circuit upon which telegraph working is superimposed by means of bridging coils is shown in Fig. 481. This plan is to be preferred where the circuit is not likely to be extended over long lines. The interpolation of the transformers seriously reduces the volume of the speaking, whilst bridging coils by reason of their

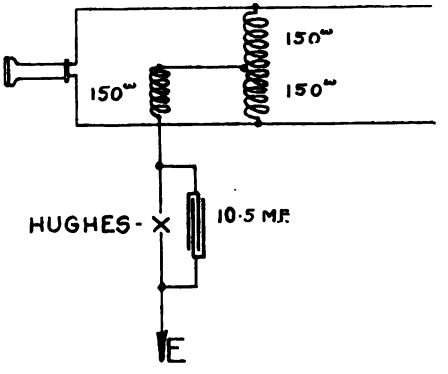


FIG. 482.—Method of superimposing Hughes circuits upon the London-Paris trunk lines.

great impedance have no appreciable effect upon it. There is, however, the disadvantage that the whole of the lines must be accurately balanced, since a very slight fault upon a line to which the telephone circuit is extended would at once cause the telegraph signals to be observed upon the telephone receiver.

The arrangement adopted for superimposing a Hughes circuit upon the London-Paris trunk lines is illustrated in Fig. 482. It will be observed that a $10\frac{1}{2}$ m.f. condenser has been placed across the terminals of the Hughes set in order to slow down the rise and fall of the current—an effect which is augmented by the action of the 150ω inductive coil. If the battery circuit had no resistance the

10½ m.f. condenser would have no effect whatever upon the sent currents, but as there is a vacuum resistance in the battery lead it considerably reduce the rates at which the current rises. The only other point which calls for comment is the arrangement of the telephone ringing circuit. Owing to the fact that the ringing current is derived from a dynamotor, which is also used to ring upon other circuits, it is necessary to prevent its direct connection to the trunk line. Many of the circuits upon which it is ringing have earth connections or possibly actual faults so that the generator becomes partially earthed—on the common battery system one side of the generator is always to earth—hence a portion of the ringing current would find its way through, and produce interferences with the telegraph circuit. In order to avoid this the depression of the ringing key is caused to connect the generator to the primary winding, and thus currents are induced in the secondary (shown in Fig. 482).

By either of the two methods considered any form of telegraph may be superimposed upon a telephone loop, but high speed working is, of course, impracticable owing to the introduction of the resistances between the battery and the lines and also to the extraordinary perfection which the lines would have to possess to prevent interference with the telephone speaking. In practice, a Steljes recorder or an A.B.C. is frequently superimposed upon a terminated telephone circuit, *e. g.* a telephone circuit connecting the Manchester and Liverpool offices of a company who also work a Steljes recorder over the loop.

Where there are several trunk lines connecting two towns their traffic-carrying capacity is greatly increased by reducing the amount of operating work taking place over them. With this object a telegraph call wire is superimposed upon one of the lines and over this is transmitted the numbers of the callings and called subscribers. In this way the distant operator can ring up the wanted subscribers and have them waiting upon the junction lines, thus saving the time of the trunk line which would otherwise be occupied in giving the number of the called subscriber, in connecting him to the junction line, and finally in ringing him up. In practice it is found that the saving is considerable—more than sufficient to justify the services of the two telegraphists.

The only noteworthy electrical features of the device consist in the use of a very small and light form of sounder contained within an ebonite case and held to the ear by means of a light steel band similar in all respects to a head gear telephone receiver. The 100ω resistance coil and the 2 m.f. condenser serve the same purpose as the corresponding parts of the Van Rysselberghe arrangement. The transmitted signals pass through the relay and galvanometer which jointly act as a graduator, it being necessary to adopt these precautions owing to the fact that the system is only used upon long trunk lines and that absolute perfection of

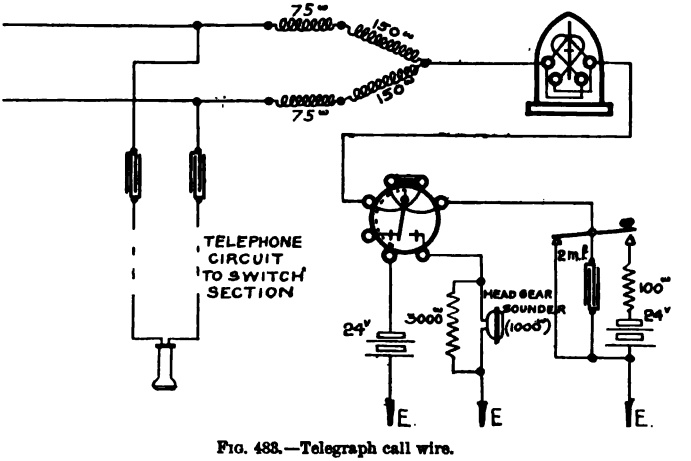


FIG. 483.—Telegraph call wire.

balance between the lines can rarely be attained in practice. The 4 m.f. condensers in the telephone circuit serve to prevent telegraph currents from passing over the junction and so producing false clearing signals at the N. T. Co.'s exchange.

There are many trunk centres at which there is but one telegraph circuit, and when this becomes faulty the town is telegraphically isolated. In such cases arrangements have been devised whereby the telegraph circuit can be superimposed upon one of the trunk lines. At small offices where the generator is only likely to be used to ring upon one circuit at a time the arrangement closely resembles that of

the telegraph call wire, save that the ordinary Morse apparatus and connections are preserved unchanged; the line is however taken through a 40ω choking coil of large inductance before connection to the centre of the transformer which is bridged across the lines precisely as in Fig. 483. A 2 m.f. condenser is bridged between the galvanometer and U-circle of the relay. Condensers of 4 m.f. capacity are as before interpolated in the trunk line on its way to the switch section. The telegraph apparatus is changed over from its ordinary line to the trunk line by means of a 9-terminal-2-position switch. At larger offices where the

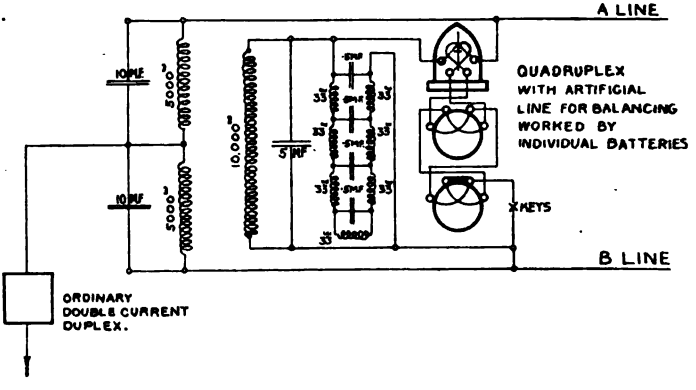


FIG. 484.—Skeleton connection of a duplex superimposed upon a metallic circuit, quadruplex working through a long subterranean cable.

generator is common to a number of sections the trunk line passes through a transformer (instead of the 4 m.f. condensers) on its way to the switch section (as in Fig. 483). The 40ω choking coil and the 2 m.f. condenser are used precisely as in the arrangement for small offices, but the change from the telegraph line to the telephone trunk is effected by test box changes instead of by a switch.

It should be stated that telegraph superimposed circuits involve the abandonment of automatic signalling upon the trunk lines upon which they work and, as has been seen, involve the interpolation of transformers at the larger offices, the exception in the case of telegraph call wires

being due to the fact that there is no ringing over the trunk line whilst the telegraphic call wire is in use for the control of the traffic. In the case of offices with but one telegraph outlet the temporary abandonment of automatic signalling and the reduction of the speaking efficiency over the trunk line is far less serious than the total dislocation of the telegraphic traffic.

It has previously been stated that duplex circuits are superimposed upon the metallic circuit quadruplexes worked through the London-Birmingham subterranean cable. This is accomplished in the manner illustrated by the skeleton diagram given in Fig. 484, from which it will be seen that the two lines are bridged by a 10,000Ω resistance coil to the centre of which an ordinary duplex set is connected. A 10 m.f. signalling condenser is placed across each of the 5,000Ω resistances in order to hasten the rise and fall of the current in duplex circuit. The quadruplex apparatus is arranged in the usual manner save that the compensation circuit is made to very closely resemble the line circuit by connecting a series of condensers of equal capacity (5 m.f.) and equal resistances (33Ω) as shown. In this way the conditions of the distributed capacity of the circuit are closely approximated—the 5 m.f. and 10,000Ω being used solely to balance the signalling condenser and its resistances. Consideration will show that, since the duplex set is worked with an earth connection over both lines in parallel, the quadruplex circuit must be worked from an individual or independent battery, and for this purpose a set of small secondary cells is provided for each circuit. It will also be realized that there is no interference between the circuits, since the operation of the duplex circuit does not affect the difference of potential between the ends of the quadruplex circuit nor does the latter, working round the loop, affect the earth-connected duplex.

The full connections are shown in Fig. 485, and call for very little comment. The duplex is known as a "plus circuit." The rheostat which bridges the ends of the artificial line serves for slight adjustments of balance, but these are extremely small, since the conditions upon an underground circuit vary but little.

The local connections of the B side relay differ somewhat from any of those previously considered. The power is

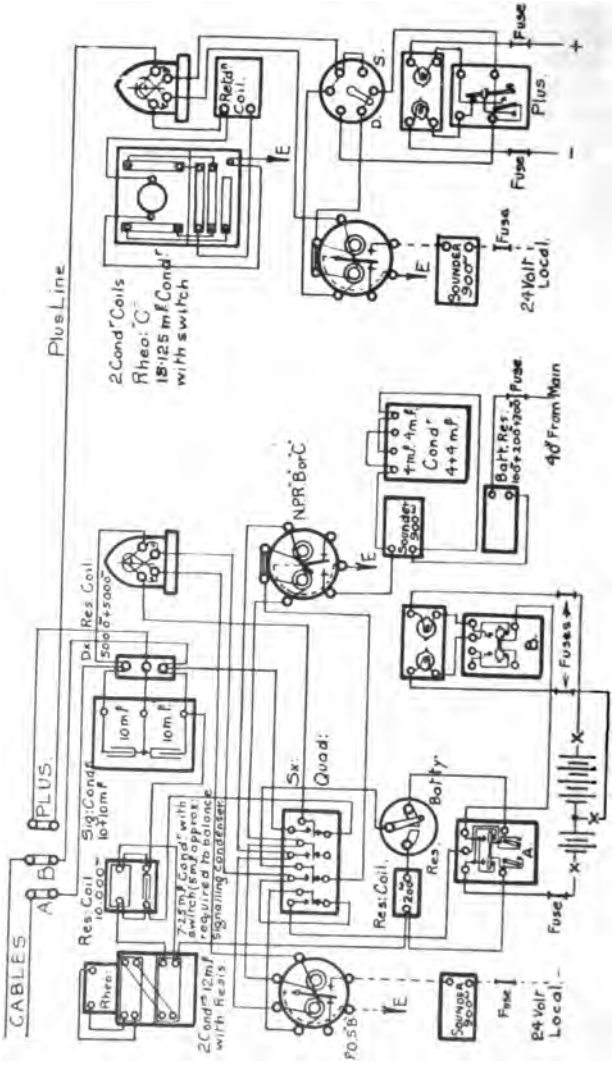


FIG. 488.—Full connections of duplex superimposed upon a metallic quadruplex circuit.

increased to 40 volts in order to permit the introduction of resistance between the battery and the condenser bridged sounder, so obviating the serious sparking which occurred in the earlier arrangements. The device has, however, quite recently been modified to that shown in Fig. 498 (*q.v.*).

SECTION D.

THE MURRAY AUTOMATIC SYSTEM.

THE description which follows is reprinted from Mr. Donald Murray's paper, "Setting Type by Telegraph" (Journal of the Proceedings of the Institution of Electrical Engineers, part 172, vol. 34), by the permission of the Editing Committee and with the sanction of the Author.

INTRODUCTORY.

The Murray differs from the Wheatstone automatic system, so far as manipulation is concerned, in the fact that a type-writer keyboard perforator is substituted for the familiar three-key type, whilst the receiver is substituted by an apparatus which, instead of inking a slip, perforates a tape in precisely the same positions as the transmitting tape. The received tape is then passed through a translator which mechanically type-writes the message in page form upon specially printed forms.

The Morse alphabet is made up of signals of unequal length, for whereas the letter "e" is represented by one unit, the figure "0" requires a space equal to 17 units; but in the Murray system each letter is of precisely the same length and is transmitted by permutations of five units. Yet another feature is that there is no space between the various letters composing a word, and the currents may, and, in fact, do actually, run together. Moreover, the system is one which merely involves isochronism, and does not, as in the Delaney multiplex, necessitate synchronism; by which latter term is meant the identity of speed and phase between the motions of two bodies at a distance. Isochronism merely requires identity of speed; that is to say, two clocks would

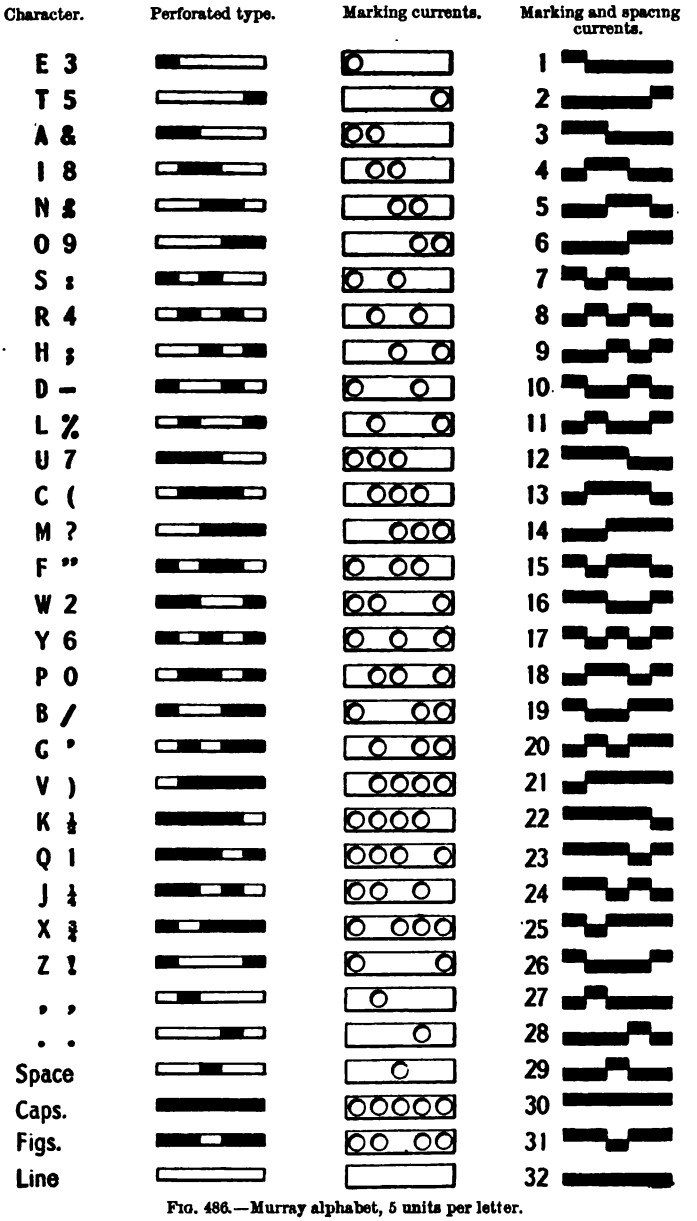


FIG. 486.—Murray alphabet, 5 units per letter.

be isochronous if the hands moved at the same speed, whereas they would only be synchronous if they also indicated the same time at every instant. The term unison is employed to denote the method adopted for correctly dividing off or distinguishing groups of letter signals.

The Murray may readily be duplexed upon the differential method, the ordinary standard condensers and rheostats being used for this purpose.

The Murray Tape, and the Correction of Errors.

Fig. 487 shows a piece of this tape perforated with holes representing the word "PARIS," while beneath it, on line

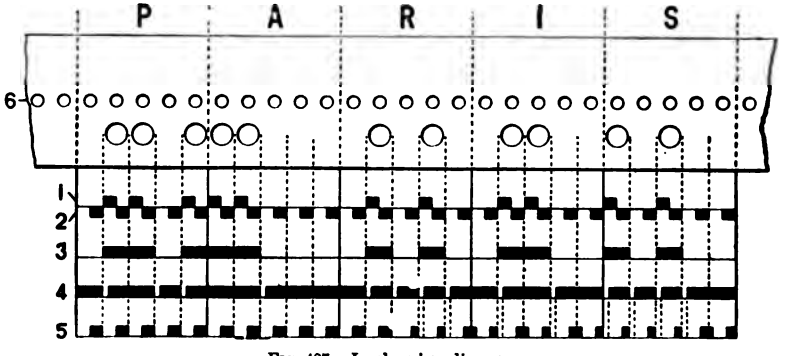
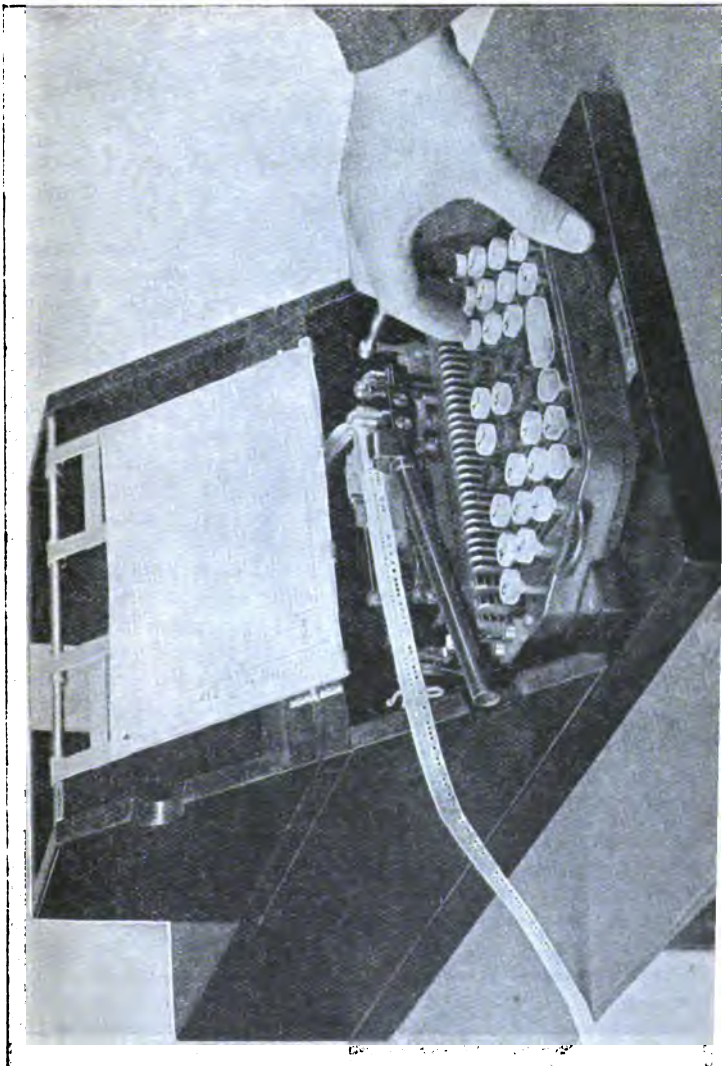


Fig. 487.—Isochronism diagram.

3, are shown the main-line time signals which this tape transmits, or which produce this tape at the receiving station. For the sake of clearness the main-line signals are shown as made up of positive and zero units. The system can be worked in this way, but it is preferable to use positive and negative units (double current), zero positions being filled with negative units. Each letter permutation occupies half-an-inch lengthwise of the tape, each letter space being divided up into five equal units. Any one or more of these units may be perforated with a message hole. This gives 32 permutations. Following the example of the Hughes and Baudot, one of these groups is used as a figure-shift and another as a letter-shift, and there are about



52 type characters. The central row of feed-holes in the tape 6, Fig. 487, is punched beforehand at an immense speed by pulling the tape through between a punch-wheel and a die-wheel.

While describing the tape, an important point in regard to automatic printing telegraphs may be explained. So far as commercial telegrams are concerned, a serious objection to direct-transmitting page-printing telegraphs is that errors show up badly in the printed message, and operators have to work slowly and carefully to avoid making mistakes. Any one who is accustomed to using a typewriter knows how difficult it is to write a page of type-written matter without striking at least one or two wrong letters. In four cases out of five there is consciousness of the error as soon as it is made, and steps can be taken to correct it. In tape-printing telegraphs, like the Hughes and Baudot, the errors and the succeeding corrections can be cut out of the tape before it is pasted on to the telegraph blank, and there is then nothing to disfigure the telegram, and make the recipient uneasy about its accuracy. With a direct-transmitting page-printing telegraph this cannot be done. A wrong key depressed is an error printed at the other end of the line, and the correction following only magnifies the blot. All automatic systems of telegraphic transmission in which there is preparation of the message beforehand possess the potentiality of correcting an error before transmission. In the Wheatstone system, for instance, this process is known as a "rub-out." In automatic telegraph systems, in which a printing machine takes the place of the receiving operator, it is a comparatively simple matter to arrange that the printer shall imitate the action of the operator by remaining inactive when dots only are coming over the line. In this way no trace of the error appears in the printed message. With automatic systems like the Murray, using an alphabet in which the letter signals are all of the same length, the transmitting tape, while being prepared in the keyboard perforator, can be pulled back instantly letter by letter by depressing a lever. If an operator strikes a wrong key, all he has to do to rectify his error is to strike the back-spacing lever, the letter-shift key, and the desired letter—the work of a moment. A word of six letters can be blotted out in this way in a few seconds, and no trace of the correction,

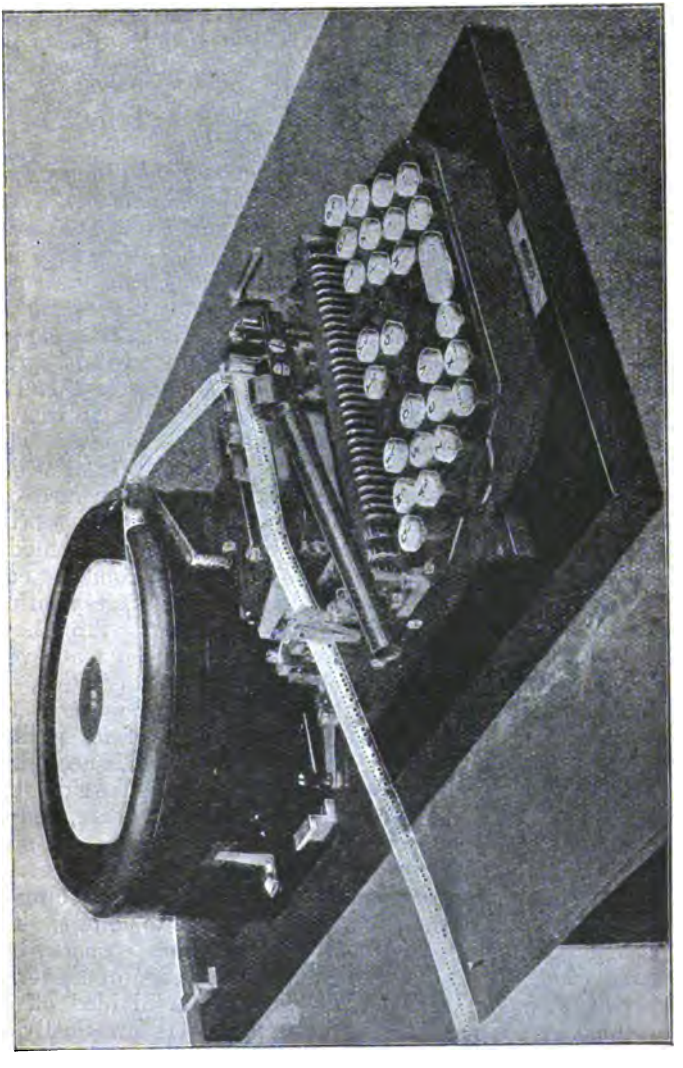


FIG. 489.—Keyboard perforator with cover removed.

not even a blank space, will appear in the printed message at the other end of the line. This relieves the operator from the dread of striking a wrong key, the strain on his attention is less, and he can work faster without working harder.

The First Translation.

The messages for transmission are punched in the tape by keyboard perforators of a very simple character. These translate the Roman letter space signals into the space signals of the five-unit telegraph alphabet. Fig. 488 is a general view of this translating instrument, with the cover on and the lid opened like a piano, ready for operation. Fig. 489 shows the instrument with the cover removed. At the back there is a box holding a condenser to suppress the spark at the punching contact. On top of this box rests the ordinary Wheatstone tape-feed wheel. In front is the actual perforator, which includes a punch-block with five punches and an electromagnet, the armature of which punches on its front stroke and feeds the tape forward one letter space on its back stroke. This magnet does the whole of the work, and there are only two electrical contacts, one a punching contact and the other a letter-counting contact, to indicate the length of the lines for the page-printing. There is also a typewriter keyboard with thirty-three keys, the touch and depression of which have been made very light and short to increase the speed of operation. A simple selecting or translating mechanism completes the machine. On the right may be seen the lever for pulling the tape back letter by letter when a correction is necessary. The correction is made by striking the letter-shift key (Caps). This punches five holes in a letter space, and so blots out all other permutations which may have been previously punched. At the other end of the line this signal leaves the printer unaffected, its function being to shift the action of the printer from figures to letters. The signal may be repeated half-a-dozen times so as to blot out a whole word, and there will be no trace of the error in the printed message. As the tape is divided off by printed cross-lines into letter spaces, it is practically as clear as print, and an operator can learn to read it in a week. It is not necessary to read the tape, but as it is

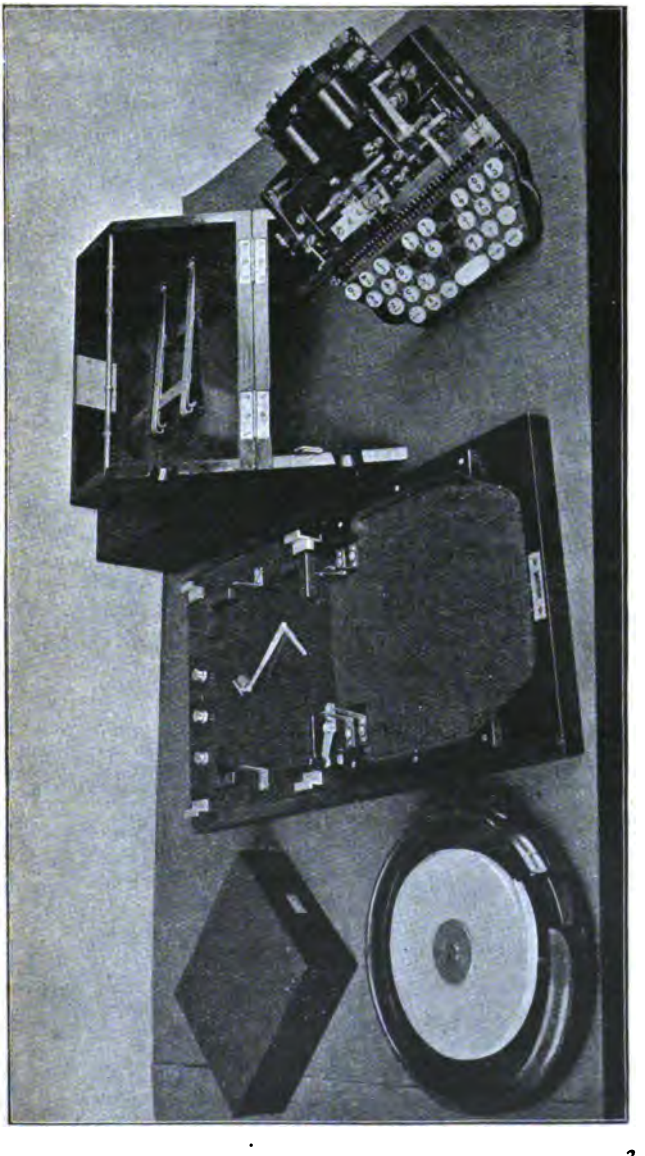


FIG. 490.—Keyboard perforator lifted apart.

easily learnt the perforator has been so designed that the perforated tape is visible up to the last letter punched just above the keyboard and below the message being perforated.

The keyboard perforators can be constructed to work on any telegraphic voltage, or on a 110 or 220 volt electric-light circuit, and the current consumption is small—about one-third of an ampere during the momentary depression of each key.

So many keyboard machines for producing perforated tape have been made during the past twenty or thirty years, that it is unnecessary to go into further details, beyond saying that the whole machine and any part of it have been made instantly removable and interchangeable. There are no screws, or terminals, or wires to be unfastened. If an instrument or any part of it is out of order, it is simply lifted away and another put in its place. Fig. 490 shows the parts separately. The key buttons are in rows of different colours, and of slightly different heights to facilitate operation without taking the eyes off the copy—an essential condition for high speed on a typewriter keyboard. This mode of working is not so difficult as might be supposed, particularly when the operator is trained from the first to write in this way.

Collection and Transmission.

The perforated tape, containing a batch of three or more messages, having been prepared, the next step is automatic transmission—that is to say, collection of the space signals and transmission as time signals.

The object of the Murray single-line transmitter is to produce, from a series of adjoining but separate holes (1, Fig. 491) in a tape, not a series of short dots like 6, but a continuous telegraphic signal 3, such as would be produced by a contact brush passing over the slit or elongated perforation 2, equal in length to all the holes 1. The mechanism has also to break or reverse the current 4 when one or more unperforated units of tape 5 intervene, and to maintain this zero or reversed current in the line until one or more perforated units of tape occur. It is a process of integrating or producing a continuous signal from a series of discontinuous holes. If it were not for

this arrangement the number of signals that would have to be transmitted to produce the Murray tape would be nearly double what it is now. It will be seen presently that at the receiving station there are instruments which exactly reverse this process. They differentiate or split up the wholesale signals into their retail units, thereby producing at the receiving station a replica of the transmitting tape.

As there is only one row of message-holes in the tape, the Murray transmitter, in its improved form, is a considerable departure from the Wheatstone model. In the Wheatstone the signals depend on the relative positions of message-holes arranged in two rows. In the new Murray transmitter the signals depend on the relative positions

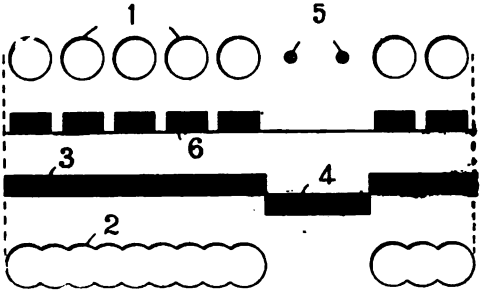


FIG. 491.—Tape signals.

of perforated and non-perforated units of tape. The mechanism is shown in Fig. 492 (collector). The tape and the transmitter together form the collector. There is the usual Wheatstone star-wheel 15 to feed the tape forward by means of the central row of holes, rack and pinion fashion; but in place of the two small upright rods used in the Wheatstone for entering the holes in the tape, there is a single rod 1. This rod is pivoted at one end of a horizontal thrust-lever 2. This thrust-lever is in its turn pivoted near its middle on a vertical lever 3, oscillating on the centre 4. This vertical lever is kept oscillating steadily by a small eccentric wheel 5 and connecting rod 6, of the same kind as that employed in the Wheatstone transmitter. The thrust-lever 2 has a tooth 7 on its under side, which rests against a pin 8 in the vertical lever 3.

The result of the oscillations of the vertical lever 3 is to cause the horizontal thrust-lever 2 to oscillate also. The free end 9 of this thrust-lever is placed close to the two free ends of two converging thrust-bars 10 and 11, which are pivoted one on each side of the pivot 12, of an ordinary Wheatstone contact lever 13. These converging thrust-bars are lightly pressed against a friction roller 14 by two small steel wire springs. The usual Wheatstone jockey roller 17 ensures the contact lever 13 making firm contact and remaining either on contact 18 or on contact 19.

When the machine is in operation, and tape perforated with a message is being fed through in the ordinary Wheatstone manner, the small steel rod 1 reciprocates regularly against the paper tape 20, as may be seen from the dotted arc 16 described from the centre 4. It makes one reciprocation for each unit of the tape, the eccentric wheel 5 making ten revolutions for one revolution of the star-wheel 15, the spindles of the two wheels being connected by ten to one gearing as shown by the large dotted circle. If there is a message-hole in the tape, the tip of the rod enters the hole and the complete motion of the rod is unobstructed. This permits the thrust-lever 2 to move as if it were one piece with the vertical lever 3, and the oscillation causes its free end to strike the free end of the lower thrust-bar 11, connected with the contact lever below the pivot 12. This throws the contact lever over on to the marking contact 18. If at the next oscillation the small upright rod again enters a hole in the tape, the same action is repeated, but the contact lever being already against the marking contact, and held there by the jockey roller 17, no change is made in its position, and marking current continues to be sent out to line. No further repetition of message-holes in the paper tape makes any change in the position of the contact lever; but if a non-perforated unit of tape intervenes, then the small rod 1 is obstructed by the tape, and the oscillation of the vertical lever 3 causes the rod 1 to depress its end of the thrust-lever 2, thereby raising the other end 9 of the thrust-lever, which then, in the course of the oscillation, strikes the upper thrust-bar 10. This throws the contact lever over on to the spacing contact 19, thereby breaking the marking current and throwing

telegraphy, including even such simple apparatus as the Wheatstone automatic, and the indicator just described leaves nothing to be desired as far as the Murray system is concerned.

Fig. 493 is a general view of the transmitter. At the back may be seen the rectangular frame of a La Cour phonic wheel motor that drives the transmitter. This motor is more clearly shown in the general diagram of the system, Fig. 492. A vibrating reed 23 sends electrical impulses alternately to the two motor magnets 24 and 25, and these keep the notched armature 26 in steady rotation. This armature 26 drives the star-wheel 15 and eccentric wheel 5. The arrangement is in reality an electrical pendulum with the action reversed, the pendulum driving the escapement wheel, the two magnets being the two pallets of the escapement which pull the escapement wheel 26 round step by step, though the inertia of the wheel is sufficient to ensure uniform motion. The vibrating reed being isochronous in the acoustical sense, the speed of the motor is the same for all amplitudes of vibration—that is to say, variation of current strength has no effect on the speed of the motor. The speed is remarkably uniform, and the motor is ideal for the purpose and gives no trouble.

This single-line transmitter has several advantages over the Wheatstone instrument, the chief one being that there is a direct thrust against the contact lever from the driving mechanism, independent of the strength of the paper tape. Hence this thrust can be made strong in order to give very firm contacts.

The Distributing Mechanism.

The distributor at the receiving station consists of two relays, a vibrating reed and a recorder. In practice the main-line signals pass through an ordinary polarized relay to earth, this relay operating two local relays; but for the sake of clearness the main-line signals are shown passing direct through the two local relays 27 and 28, Fig. 492, to earth. It is by means of these two relays that the rest of the distributing mechanism is controlled. The recorder, which punches the message-holes in the receiving tape, is also shown in Fig. 492. This recorder consists of a punching magnet and a spacing magnet. The punching magnet

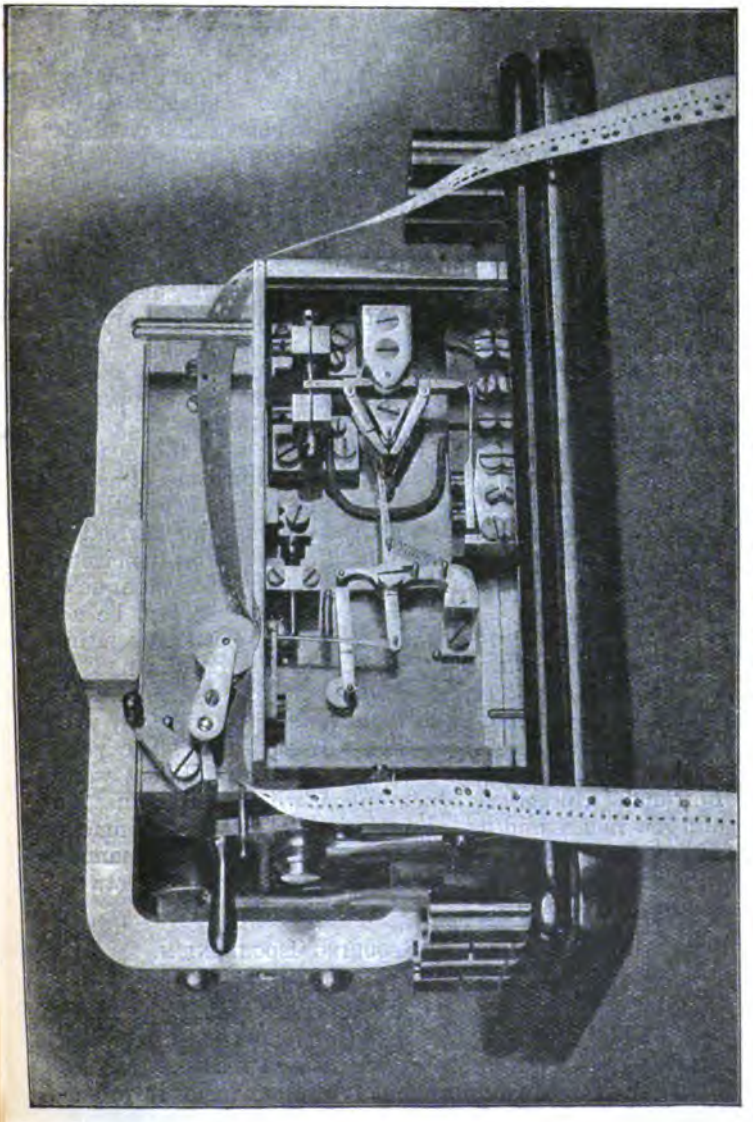


FIG. 498.—Single-line transmitter.

operates a punching lever 29 and a punch 30. This punch corresponds with the small rod 1 in the transmitter. The punch reproduces the motions of the rod, and thereby reproduces the perforations in the tape. On short circuit the punch and the rod may be seen to be working precisely in step with each other. The spacing magnet feeds the tape forward unit by unit by means of the escapement and star-wheel on the motor-driven spindle 31. In order to secure the alternating action of these two magnets, the contacts which close their respective circuits are arranged one on each side, 32 and 33, of a vibrating reed 34, driven by a magnet 35. As the reed vibrates, short impulses are sent alternately to the punching and the spacing magnet. When there are no signals passing in the main line, a special device (not shown) cuts out the spacing magnet by opening the switch 60, and so stops the tape; but as long as a message is passing the vibratory action of the spacing magnet is continuous, and the tape is fed forward at a fixed speed. The punching magnet works alternately with the spacing magnet, but only when there is marking current in the main line, the punching relay 27 controlling the circuit of the punching magnet. The oscillations of the tongue of relay 27 and of the vibrating reed must therefore be not only isochronous, but also synchronous. Between sending station and receiving station isochronism only is needed, but between the receiving instruments on the same table synchronism is essential. This is the case not only with printing telegraphs, but with all machines. The parts must move synchronously or the machine will not work. Fortunately, practical synchronism, when it is a question of a few inches and not of miles, is very easy of attainment. In the Murray system it is achieved in the following manner, which also of course secures the needful isochronism between the two stations.

The Method of Securing Isochronism.

The reed 34, kept vibrating by the magnet 35, beats against buffer springs 36 and 37. These limit the amplitude of vibration, and, as the energy imparted to the reed must find some outlet, the frequency is increased. Without buffer springs the amplitude of vibration varies in proportion to the strength of the current through the reed magnet,

but the frequency is wonderfully uniform. The reed is then isochronous in the acoustical sense. With a fixed amplitude determined by the buffer springs the frequency varies with the strength of the current. The reed is no longer isochronous. Its speed becomes very sensitive to variations of current, and can therefore be controlled by controlling the current to the reed magnet. If the circuit of the reed magnet 35 is traced from the battery 38, it will be found that it has two break-points—one at the contact of the tongue 39 of the governing relay 28, and the other at the reed contact 40. The punching and governing relays are identical in all respects, and they are driven by the same power, so that their synchronism is perfect. (They correspond to driven wheels only a few inches apart.) The tongue 39, therefore, moves in exactly the same time as tongue 41. Hence as long as tongue 39 oscillates synchronously with the reed, tongue 41 will do the same—in fact, the two relays might be replaced by one relay with two tongues. The back and front stops, 42 and 43, of the governing relay are electrically united, so that at the beginning and end of a main-line signal when the tongue of the governing relay crosses from one contact to the other, there is a momentary break in the reed magnet circuit during the time of the transit of the tongue. This transit time can be varied to a considerable extent by adjusting the position of the contact stops. Opening the contacts increases the governing effect, and closing them diminishes it. The reed magnet 35 breaks its own circuit at 40 in the usual vibratory way. If the reed 34 is oscillating in synchronism with the relay tongue 39, then full vibratory impulses will flow through magnet 35, as the two contacts at 39 and 40 will be opened and closed simultaneously. But if the reed tends to go faster than the arriving signals, then the two contacts 39 and 40 no longer open and close together, but more or less alternately, and the current impulses in the magnet 35 are more or less clipped. This reduction in the supply of energy to the reed at once reduces its speed till the contacts are again simultaneous. In practice the receiving vibrator is set to run about 2 or 3 per cent. faster than the arriving signals, and the governing action of the two interfering break-points in the same circuit results in the establishment of a steady dynamic balance between the accelerating tend-

ency of the reed and the retarding tendency of the arriving signals. The effect is exactly the same as that produced by two taps in a water-pipe. If both are opened and closed together the water flows through in gushes; but if they are opened and closed alternately no water gets through, and more or less water gets through accordingly as the taps are opened and closed more or less alternately. By this means the relay tongue 41 not only vibrates at the same speed as the reed 34, but preserves the same phase—that is to say, tongue 41 touches contact 44 at the same time as the reed touches contact 33, even when the reed is making seventy-five vibrations per second (150 words per minute). But the tongue 41 does not move for every vibration of the reed. For instance, if there is a 4-unit marking signal coming over the main line, then the tongue 41 closes on its punching contact 44 for an interval of 4 units' duration, and the reed then makes four vibrations, touching the contact 33 four times, and in this way punching four successive holes in the tape by the alternate actions of the punching and spacing magnets. The transit intervals of the tongue of the governing relay 28 might be said to be like the teeth of an old saw. Some are there and some are not, but such as remain are all at unitary distances from one another (see line 4, Fig. 487). So also with the signals, and there are always enough signals to govern. Actually one correction per letter is sufficient, but on the average there are not less than two and a half, because each main-line signal gives two corrections, one at the beginning and the other at the end of the signal. As a matter of fact, the governing action may be stopped during the arrival of as many as six or eight letters without upsetting the isochronism, and if a line disturbance or other cause throws the reed out of step, it comes in again within five letter spaces—that is to say, in half a second at a hundred words a minute. The reed is only in step as long as signals are coming over the line, and it goes out of step at the end of a batch of messages, but five space signals at the beginning of a new batch of messages bring it in again ready to record the messages. By this arrangement the necessity for sending correcting impulses over the main line to secure isochronism is avoided, the correcting impulses being generated locally from the arriving letter signals themselves. In this respect

the Murray system has followed the excellent example set by the Hughes.

The isochronism diagram, Fig. 487, illustrates the co-operation of the current impulses. It shows a section of receiving tape punched with the word "PARIS." Beneath are the current impulses, indicated by black bars. Line 1 shows the impulses given to the punching magnet by the successive contacts of the reed 34 with the contact 33. Line 2 shows the uninterrupted succession of impulses to the spacing magnet from the reed contact 32. Line 3 shows the main-line signals. This illustrates the great saving of line signals effected by the special arrangements of the collecting and distributing mechanisms. Without these special arrangements it would be necessary to transmit over the main line the signals shown in lines 1 and 2, that is to say, about five times as many signals as are now required. Line 4 shows the gaps in the circuit of the reed magnet 35 made by the crossing from contact to contact of the tongue 39 of the governing relay. Line 5 shows the impulses generated by the reed contact 40. As long as these impulses do not get into step with the gaps in line 4 they are not interfered with; but directly they do they get clipped, as shown for the sake of illustration in the second half of line 4. The speed at the two stations can, of course, be varied by altering the position and size of the weights on the vibrating reeds at the two stations.

A speed of no less than 900 letters (150 words) per minute in one direction has been reached with this recording mechanism, at which speed the punching magnet has to punch seventy-five holes per second, and the punching and spacing of the receiving tape have been perfectly performed at 960 letters (160 words) per minute, or eighty holes per second. Even this is not the limit, and it is possible that the speed might be forced up to even 1,200 letters (200 words) per minute. As half the time is required for spacing, the punching of eighty holes per second means that the punching magnet operates in $\frac{1}{160}$th of a second. As it takes a pressure of about 2 lbs. to force the punch through the paper, the punching magnet can not only operate with considerable speed, but also with considerable power. For ordinary commercial telegraphy there is no necessity for such high speed, and it is probable that, if the Murray

system comes into general use in preference to other systems the speeds required will be from about 240 letters (40 words) up to about 720 letters (120 words) per minute.

The transmitted signals having been correctly distributed along the receiving tape 45, Fig. 492, by the recording mechanism just described, the tape may then be used in its turn for again transmitting the signals over other circuits, or it may be run through the printer to translate the signals into printed letters. As the signals when retransmitted are sent on in as perfect shape as from the original transmitting station, it is possible to transmit messages in this way at a high speed to any distance overland—from London to Calcutta, if need be. Owing to the power to retransmit from the received tape, it is also possible to transmit messages from any number of stations A, B, C, to station D, and to sort out the messages there and retransmit automatically in accordance with the addresses to any stations E, F, G, any one or more of which may again retransmit messages requiring to be sent on still further.

The Second Translation and Printing.

If the tape is not required for retransmission, then the tape signals have to be translated into Roman letters and printed. The essential features of the Murray printer are shown in the general diagram, Fig. 492. The tape is fed along letter by letter (five units at a time) by a star-wheel 46, carried on a shuttle 47, which is kept reciprocating in the directions shown by the double arrow A-B, by means of a cam, each reciprocation rotating the star-wheel one letter space as shown by the arrow C-D. The shuttle carries a die-plate coinciding with the circumference of the star-wheel, and having five holes corresponding with the message-holes in the tape. Five rods 48, fixed in the ends of five slotted combs 49, are free to enter the five holes in the die-plate if they are not obstructed by the paper tape which passes between the rods and the die-plate. On its inward stroke the shuttle with its die-plate presses the tape, with a letter group of perforations, against the ends of the five rods 48. Rods that are opposite holes in the tape pass through into the die-plate, and the positions of the corresponding combs are not altered. But in the case of non-perforated units of

tape the corresponding combs are thrust back about $\frac{1}{16}$th of an inch. By this means one particular group of slots in the combs, and only one out of fifty-six is brought into alignment so that a latch or cross-bar 50 can drop into it. Although only four latches are shown, there are fifty-six of these small levers, one for each of the fifty-six permutations or groups of slots. The latches or cross-bars are supported by a universal bar 51 just clear of the teeth of the combs. At the right moment this bar drops in the direction of the double arrow F-E and leaves all the cross-bars resting on the combs ; but only one out of the fifty-six is selected by the particular aligned group of slots corresponding to any particular group of holes in the tape.

From the point of view of the theory of machines, the combs form a complicated system of fifty-six inverse permutation locks. The fifty-six cross-bars are the bolts or latches, and the universal bar 51 is a universal key. The locks are continually being closed in different ways by the tape, and the universal key 51 is continually opening the locks. The tape, however, is only an intermediary. The locks are really closed selectively by the keys of the perforators at the transmitting station, the keys of the perforators being real keys in the ordinary sense of the word, and not nominal keys like those of a typewriter. The letter signals sent over the line are an exact copy of the wards of the keys of the keyboard perforators. This intricate system of keys and locks is inevitable in all cases where complex control is needed.

Let us assume that latch or cross-bar 50 in Fig. 492 has been selected. This cross-bar, under the action of its spring 52, throws a hook 53, attached to a typewriter key 54, under a striker-bar 55, which is continually oscillating in the directions shown by the double arrow G-H, and the typewriter key is in this way sharply depressed so as to print. The object of this arrangement is to secure speed and smoothness of action. The moment the hook 53 is engaged by the striker-bar 55, the system of locks can be opened by the universal bar 51 and close again with a fresh letter permutation simultaneously with the printing of the last letter. This arrangement practically doubles the speed of the printer. The shuttle on its outward stroke restores the combs to their original positions by means of

the plate 56, which engages with inward projecting teeth on the overhanging ends of the combs. The cycle of operations, including the rotation, at the right moment, of the star-wheel 46 through one letter space, the reciprocation of the shuttle 47, the reciprocation of the universal key-bar 51, the oscillation of the striker-bar 55, and the return of the combs to zero position ready for the next letter, is performed by a battery of cams.

Although in the Murray printer there are only five

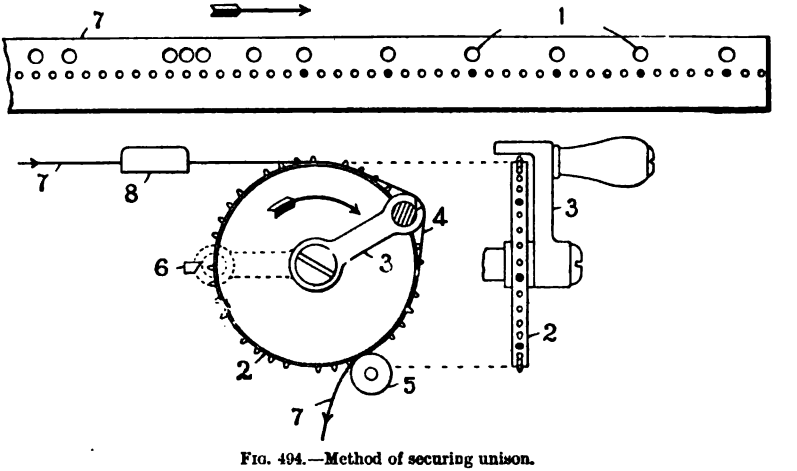


FIG. 494.—Method of securing unison.

combs with rods 48, there is a sixth comb 61, which in one position causes figures to be selected and in the other position letters. It is operated by two special cross-bars, one each end. This arrangement is shown more clearly at A, Fig. 492. At each end of this comb will be noticed a V-shaped slot, and the two cross-bars shown in section at 57 and 58 carry wedge-shaped pieces for striking the edge of these V-shaped slots. When a figure-shift signal is transmitted, it selects the figure cross-bar 58. This drops into its group of slots, strikes against the sloping edge of the figure-comb slot, and moves the comb $\frac{1}{16}$th of an inch to the left in the direction J, thereby opening the figure-locks and closing the letter-locks. A letter-shift signal

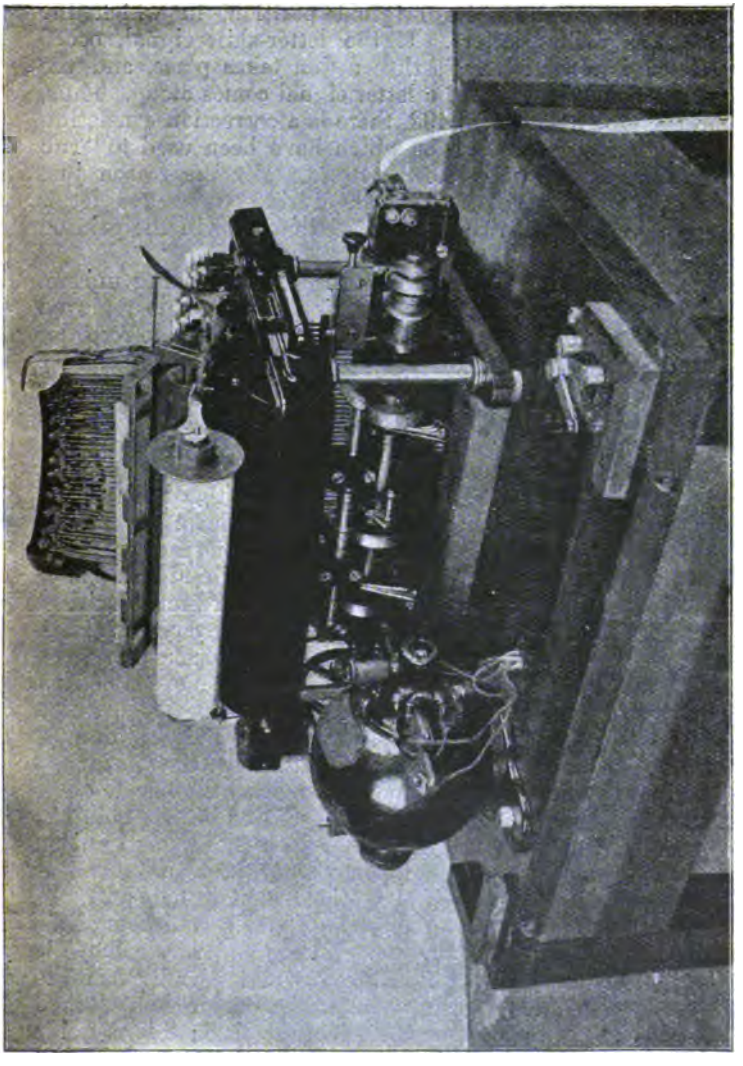


FIG. 495.—Murray printer complete with typewriter.

succeeding a group of figures operates 57, which restores the figure-comb to its original position, in which the machine prints letters. If the letter-shift signal, ooooo (Caps), is repeated, no further action takes place, and the printer remains idle till a letter signal comes along. Thus, in the tape at 59, Fig. 492, there is a correction consisting of five letter-shift signals, which have been used to "rub out" a wrong word of five letters. For the reason just given the printer remains idle during these five letter spaces, and there is no trace of the error in the printed message.

An interesting point is the method of securing unison. In the Murray system the question of unison is removed from the line to the tape. As with the Wheatstone recorder tape, it is a question of correctly dividing up the signals on the tape. With the five-unit alphabet each letter occupies five units, or half an inch on the tape. Hence to divide up the signals properly we have to start at the right unit and then measure 5 units at a time. The star-wheel 46, Fig. 492, does the measuring, and all that is necessary is to place the tape properly on the star-wheel. To enable this to be done with facility, each batch of messages begins with four or five space signals, as shown in Fig. 494 at 1. The space signal is a perforation in the third-unit position. In the star-wheel 2 it will be noticed that every fifth tooth is omitted and the vacant tooth positions blackened. The tape 7 is inserted in the machine so that the space holes 1 come opposite the missing teeth of the star-wheel, which show up black through every fifth central hole in the tape, as shown for the sake of illustration by the blackened centre holes in the tape opposite the space signals 1. The tape is then in unison. In the event of its not being in unison, it can be put in step by rotating the small unison arm 3. This bags up the tape as shown at 4, and advances the tape on the star-wheel to the extent of one unit. A maximum of four and an average of two revolutions of the unison arm 3 brings the tape into step. The roller 5 is spring-pressed, so that it gives way and permits arm 3 to pass. The unison arm when not in use is held locked in the dotted position by the spring-tooth 6; 8 is a guide for the tape. The missing teeth in the star-wheel and the space signals show at a glance at the beginning of a

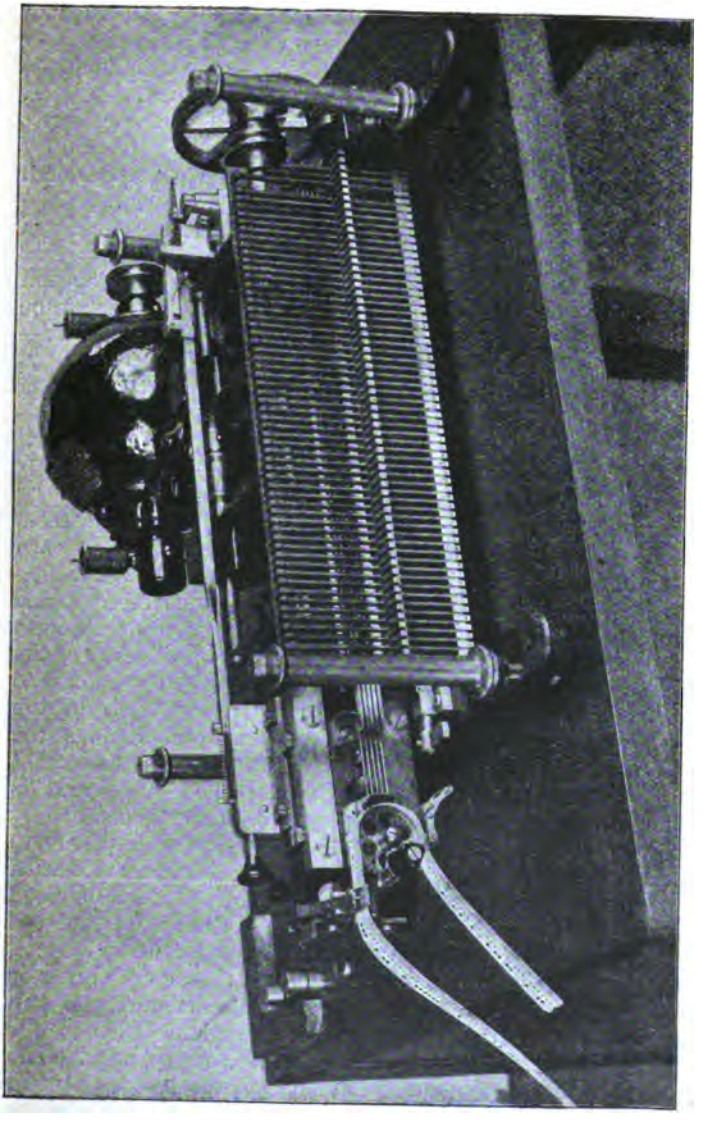


FIG. 496.—Murray printer with typewriter removed.

message whether the tape is in step. If a line interruption causes the unison to fail in the middle of a message, two or three revolutions of the unison arm by the attendant sets all right again. This does not often happen, however, as a line interruption must be complete for at least seven letters before the unison can be affected. Momentary interruptions do not disturb it. Apart from occasional line interruptions the receiving mechanism perforates the tape with surprising accuracy. On short circuit it will run for hours without making a single false perforation.

In regard to the printing of the messages on telegraph forms, there are four motions of the sheets of paper to be provided for, two horizontal and two vertical, as follows :—

Horizontal	{	Letter feed. Line feed.
Vertical	{	Column feed. Page feed.

The letter feed is already performed automatically by the typewriter. To provide for an automatic line feed, there is a small letter-counting device on the keyboard perforators. This indicates the end of a typewriter line of about seventy letters. A key is then depressed which punches a line signal in the tape. This is transmitted to the receiving station, where it operates a special key of the typewriter, which throws in a clutch, causing automatic mechanism to pull the typewriter carriage back to the beginning of the line. The same action provides the column feed up to a new line by a simple arrangement used in most modern typewriters. The page feed is more complicated and has not yet been made completely automatic in any printing telegraph, although there are several automatic page feeders giving good service with printing presses. In fact, many of the modern illustrated magazines are printed automatically from a pile of cut sheets by this means. At present, in the Murray system, the page feed is managed as follows: A stop signal is transmitted on the tape at the end of each message, and this not only runs the typewriter carriage back to the beginning of a new line, but also stops the printer. The attendant then pulls out the finished message by hand, and by a simple device it automatically tears off at the right

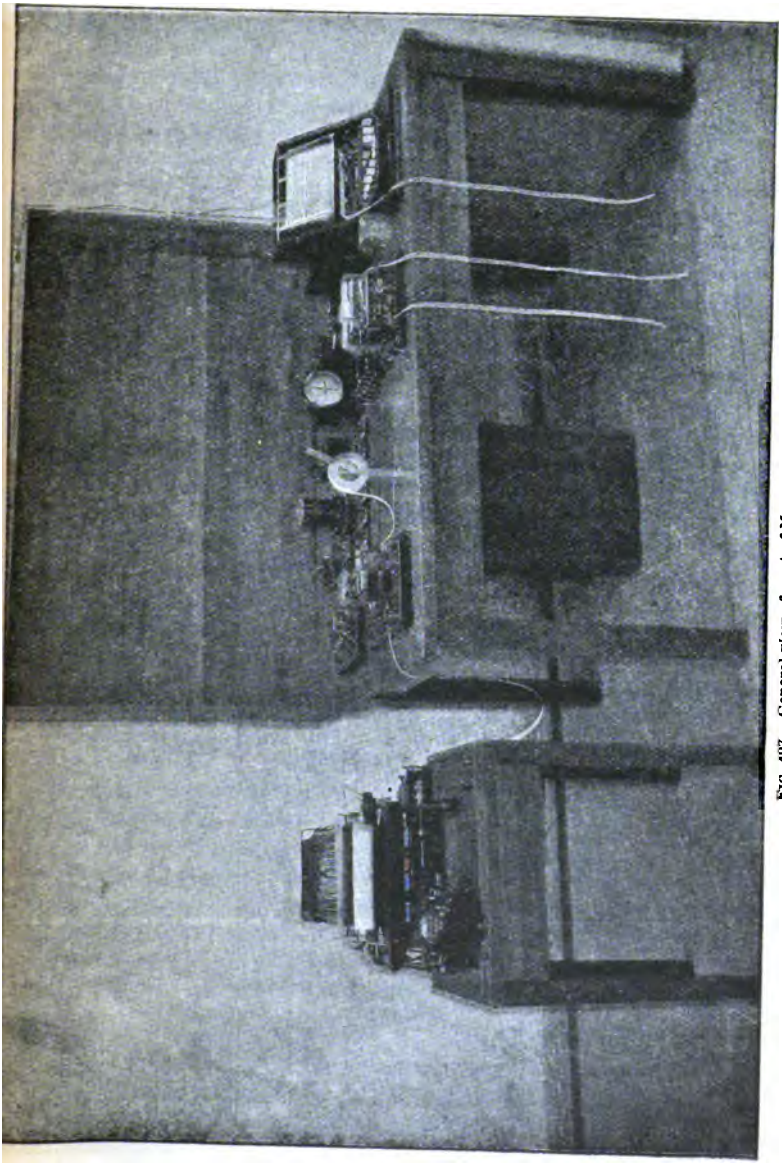


FIG. 497.—General view of a set of Murray apparatus.

point, leaving the next telegraph blank pulled in to the right starting point. The attendant then presses a button, which starts the printer on the next message. The process is quite rapid. Later on it may prove worth while to make the page feed completely automatic. The printer will then feed itself from a pile of cut telegraph blanks, and toss out the finished messages like tickets from a cash register. The chain of mechanisms will be completed by an automatic folding and enveloping machine, which will fold the telegrams and thrust them into transparent envelopes and seal them so that only the addresses will show through.

The printer, two views of which are shown in Figs. 495 and 496, is now driven by a small motor consuming about 40 watts for a speed of 140 words per minute. This motor also supplies the power for automatically returning the typewriter carriage to the beginning of a new line. Fig. 497 is a general view of a set or "station" of the apparatus. Only one keyboard perforator is shown; but in practice three or four are needed.

Capacity of the Murray System.

The speed of the printer is now not less than 900 letters (150 words) per minute, and the automatic portion of the mechanism runs perfectly up to about 200 words a minute. Unfortunately, however, no typewriter yet constructed will stand the strain of more than about 720 letters (120 words) a minute in continuous service. The received tape may be divided into sections and run through two printers when the apparatus has to be worked at top speed. Under existing conditions, however, high speeds for handling commercial messages are for many reasons undesirable, and a maximum of 120 words a minute in each direction seems to meet all requirements.

SECTION E.

QUADRUPLEX CIRCUITS, NEW STANDARD ARRANGEMENTS.

OWING to sparking at the relay contacts and to other causes, the "B" side arrangement shown upon page 277 was modified to that illustrated upon page 824, but this has quite recently been improved by adding a 50ω resistance coil and by placing the adjustable resistance coils in the

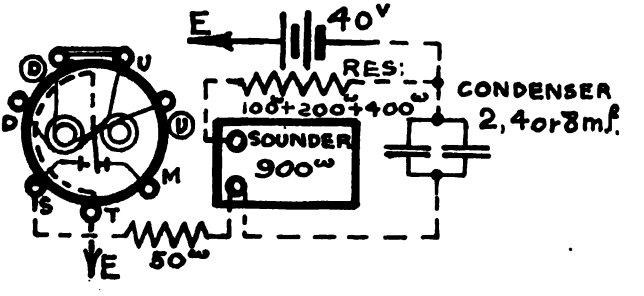


FIG. 498.—Latest arrangement of the "B" side.

path along which the condenser acts (Fig. 498). The 50ω coil has for its object the prevention of sparking due to the heating of the contacts which would result from the heavy rush of current *viâ* the condenser when the circuit was completed. The capacity of the condenser (Fig. 499) may be made either 2, 4, or 8 m.f.s, according to the necessities of the particular line, whilst the resistance may be varied from 100 to 700ω by gradations of 100ω. In this way the duration of the discharge of the condenser and

self-induced current from the sounder coils may be modified, thus increasing or reducing the time during which the magnetization of the sounder cores is maintained when the circuit is broken. It may be added that the device has proved eminently satisfactory, and that the difficulties encountered with the earlier methods have been entirely eliminated.

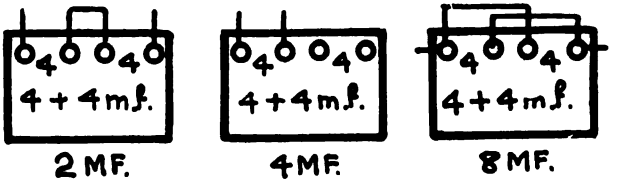


FIG. 499.—Methods of joining up the condenser.

The full connections of a quadruplex up station worked with primary batteries are shown in figure 501. It will be observed that a 9-terminal-2-position switch has been added, and that its functions are similar to those of the 4-bar switch shown on page 507. When the switch is turned to simplex its connections are as indicated in Fig. 500, with the results :—(1) D and U-circle of the non-polarized relay are directly connected; (2) the right terminal of the "A" key is disconnected from the split and connected to the lower right hand terminal of the galvanometer, and (3) the centre terminal of the key is joined to D of the "A" side relay. It will therefore be apparent that, in simplex working, the received current passes through the line coil of the galvanometer, both coils of the A side relay only, through the compensation circuit coil of the galvanometer and rheostat to earth whilst the sending current passes to line through the line coil of the galvanometer.

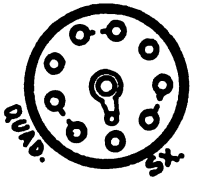


FIG. 500.—Switch connections at simplex.

Upon circuits under 100 miles in length the battery power upon the "B" side local circuit consists of 13 Bichromate cells, whilst above that length 22 cells are used. The resistance coil marked "B" in Fig. 501 has a resistance of 50 plus the resistance of the "B" side battery,

whilst the coil C should have a value equal to the resistance of the coil A and the whole battery. The "A" key should be of the latest type with adjustable contacts and

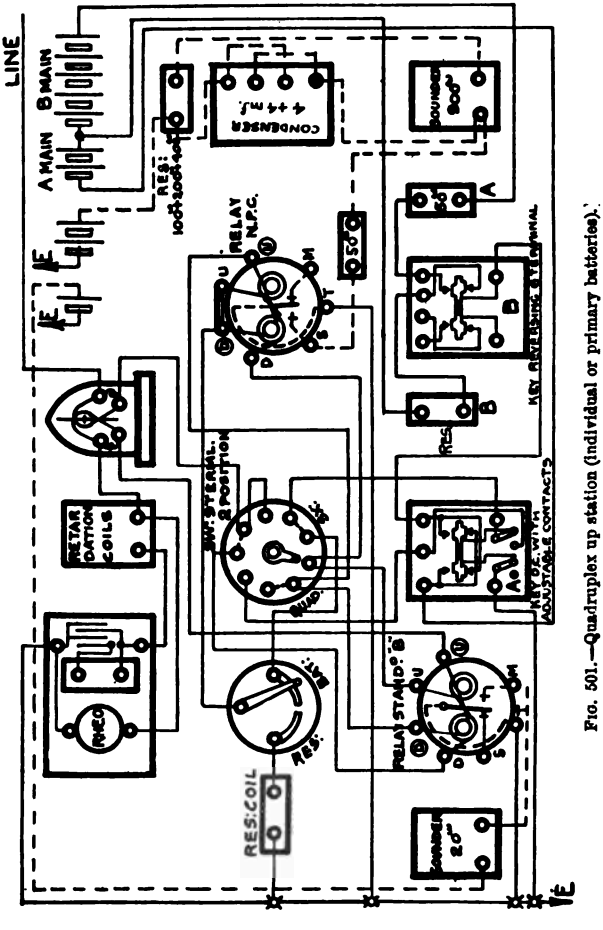


FIG. 501.—Quadruplex up station (individual or primary batteries).

should momentarily short-circuit the battery during reversal.

The connections required at a down station are obtained

by reversing (1) the wires on the upper and lower terminals of the galvanometer; (2) by the wires on D and U circle of the relay; and (3) the battery connections of the "A" side key.

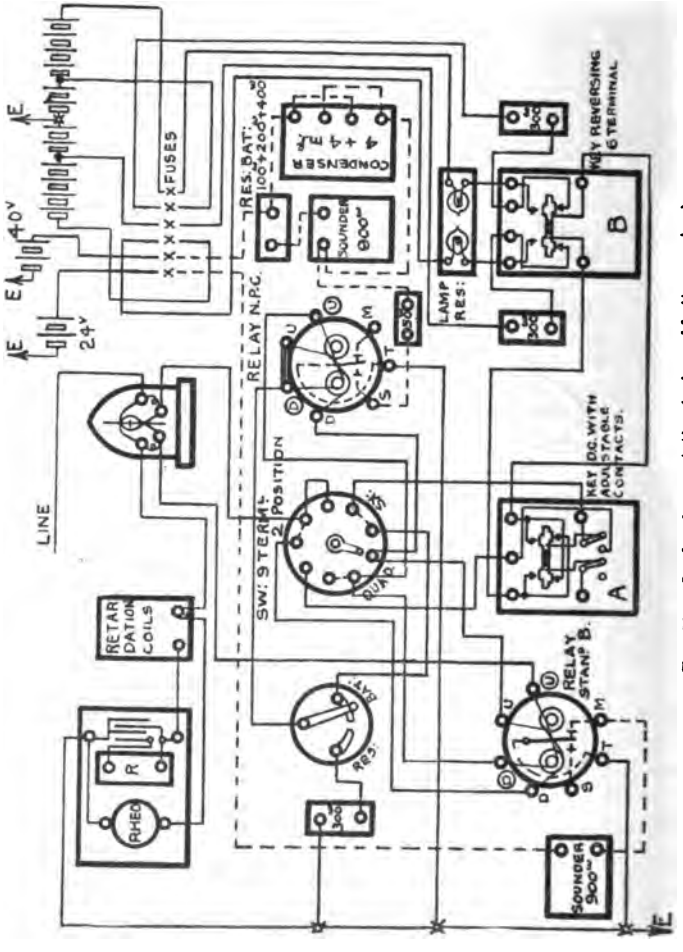


FIG. 502.—Quadruplex up station (universal battery system).

Wheatstone working upon the "A" side may be provided for, but, as the connections required are quite obvious,

no further comment should be necessary. In special cases the principle illustrated in Fig. 293, page 510, is occasionally adopted, a neutral relay and a relaying sounder being employed increase the power upon the B side when the transmitter is running.

A universal battery worked quadruplex up station is depicted in Fig. 502, from which it will be observed that a 9-terminal-2-position switch takes the place of the 4-bar switch shown on page 508. The switch for measuring currents has been omitted in the latest arrangement, as also has the bridging coil, the latter being necessary only upon very short circuits (see page 507). The "B" side is arranged precisely as in Fig. 501, and there is nothing which is not quite obvious from the previous consideration of Figs. 292 and 501.

Wheatstone working upon the A side is readily provided, and there is nothing in the connections which calls for comment save that in special cases the principle illustrated upon page 510 is employed to increase the power upon the B side whilst the transmitter is running. In the latest arrangement the only changes from the connections shown on page 510 are, (1) the substitution of a 9-terminal for the 4-bar switch; (2) the omission of the "current measuring" switch; (3) the omission of the bridging coil; (4) the substitution of the "B" side local circuit shown in Fig. 498. It will be obvious that, in this case, the upper contacts of the divided lever must not be withdrawn, since they are employed to complete the circuit of the neutral relay when the transmitter is running.

SECTION F.

EXAMPLES ON THE CALCULATION OF THE CAPACITY OF CIRCUITS.

THE average value of the capacity K in microfarads of an aërial wire d mils in diameter, h mils above the ground, and l miles in length, may be obtained from Kempe's formula :—

$$K = \frac{\cdot 0616\, l}{\log \frac{4h}{d}}$$

The number ·0616 is an experimentally determined constant and refers to wires erected in this country.

Example. What is the average capacity per mile of a 70 lb. bronze wire (diameter 66 mils) suspended 30 feet above the ground ?

$$K = \frac{\cdot 0616 \times 1}{\log \frac{4 \times 360{,}000}{66}} = \frac{\cdot 0616}{4.34} = \cdot 0142 \text{ m.f.}$$

The capacity K in electrostatic units of two co-axial cylinders l cms. long separated by a material having a specific capacity k, where D is the outside diameter of the inner, and d the inside diameter of the outer, cylinder is given by the formula :—

$$K = \frac{l\, k}{2 \log_e \frac{D}{d}} \quad *$$

* The proof of this formula, involving a simple application of calculus, is given in the more advanced of the elementary treatises on electricity ; see J. J. Thomson's "Elements of the Mathematical Theory of Electricity and Magnetism," page 93.

This formula may be applied to the case of a cable core, and taking, for example, a mile of 7½ G.P. wire ($D = 174$ mils, $d = 50$ mils, and $k = 4{\cdot}2$), and putting the whole of the dimensions in centimetres, the capacity

$$= \frac{1760 \times 36 \times 2{\cdot}54 \times 4{\cdot}2}{2 \log_e \frac{{\cdot}174 \times 2{\cdot}54}{{\cdot}05 \times 2{\cdot}54}} \text{ electro-static units.}$$

Dividing by 9×10^5 to convert the result in static units to microfarads, and also multiplying the denominator by 2·3026 to convert the natural into a common logarithm, the capacity is

$$= \frac{1760 \times 36 \times 2{\cdot}54 \times 4{\cdot}2}{2 \times 2{\cdot}3026 \times \log_{10} \frac{{\cdot}174}{{\cdot}05} \times 9 \times 10^5} = {\cdot}301 \text{ m.f.}$$

a result which agrees very closely with the specification (see page 515.)

As a further illustration of this formula it will be interesting to apply it to the case of a screened conductor cable, and so determine the approximate specific capacity of the air and paper dielectric (all paper with exception of the small helical air space)—

$$k = \frac{K}{l} \frac{2 \log_e \frac{D}{d}}{} \text{ where } K \text{ is in static units.}$$

Substituting the figures for a 230 mil core having a 50 mil conductor, expressing the capacity of one mile of cable (·095 m.f.) in static units, and converting to common logarithms :—

$$k = \frac{{\cdot}095 \times 9 \times 10^5 \times 2 \times 2{\cdot}3026 \times \log \frac{{\cdot}230 \times 2{\cdot}54}{{\cdot}050 \times 2{\cdot}54}}{1760 \times 36 \times 2{\cdot}54}$$

$= 1{\cdot}62$ as compared with the 4·2 of G.P.

A few simple problems based upon the formula for the capacity of two co-axial cylinders are given by way of conclusion—

Example I. Find the relative capacities of two G.P.

cables of equal length, A having a conductor 100 mils in diameter and a core of 200 mils, whilst B has a 200 mil conductor and a 500 mil core (log 2 = ·30103)—

$$A : B :: \frac{l\,k}{2 \log_e \frac{200}{100}} : \frac{l\,k}{2 \log_e \frac{500}{200}}$$

$$i.e.\ A : B :: \log \frac{10}{4} : \log 2$$

$$:: \log 10 - \log 4 : \cdot 30103$$

But $\log 10 = 1$ and $\log 4 = 2 \log 2$

$$\therefore A : B :: \cdot 39794 : \cdot 30103$$

Example II. Find the relative capacities of one mile of G.P. covered cable, A 80 mil conductor and 100 mil core and B 120 mil conductor and 180 mil core, given log 2 = ·30103 and log 3 = ·47712—

$$A : B :: \log \frac{180}{120} : \log \frac{100}{80}$$

or $$A : B :: \log \frac{3}{2} : \log \frac{10}{8}$$

or $$A : B :: \log 3 - \log 2 : 1 - 3 \log 2$$

$$A : B :: \cdot 17609 : \cdot 09691$$

Example III. Compare the working speeds of two G.P. cables of equal length A, having a 60 mil conductor with a total diameter of 100 mils, and B having a 100 mil conductor insulated with G.P. 85 mils thick (log 2 = ·30103 and log 3 = ·47712).

Notes. The working speeds may be assumed to be inversely proportional to the KRs, and as the lengths are equal the resistances are inversely proportional to the squares of the respective conductor diameters. The total diameter of the core B = 270 mils—

Let R_A, R_B, K_A, K_B, S_A, S_B, represent the resistances, capacities, and speeds of the cables.

$$R_A : R_B :: 100^2 : 60^2$$

$$K_A : K_B :: \log \frac{270}{100} : \log \frac{100}{60}$$

or $K_A : K_B :: 3 \log 3 - 1 : 1 - (\log 3 + \log 2)$

i.e. $K_A : K_B :: \cdot 43136 : \cdot 22185$

$S_A : S_B :: K_B \times R_B : K_A \times R_A$

$S_A : S_B :: \cdot 22185 \times 100^2 : \cdot 43136 \times 60^2$

i.e. $S_A : S_B :: 2218 \cdot 5 : 1553 \cdot 9$

Example IV. What must be the thickness of the G.P. insulation in order that a 100 mil conductor shall have the same capacity per unit length as a 120 mil conductor having a core diameter of 200 mils ?

$$\log \frac{200}{120} = \log \frac{x}{100}$$

$$\therefore \frac{200}{120} = \frac{x}{100}$$

$$i.e.\ x = 167 \text{ mils}$$

The thickness of the G.P. covering is therefore—

$$\frac{167 - 100}{2} = 33\tfrac{1}{2} \text{ mils.}$$

SECTION G.

USEFUL NUMBERS.

Conversion of Lengths, Weights, etc.

1 inch	=	2·54 centimetres	1 cm.	=	·3937 in.
1 yard	=	91·44 centimetres	1 metre	=	39·37 ins.
1 mil.	=	·0254 millimetres	1 mm	=	39·37 mils.
1 sq. in.	=	6·4516 sq. cms.	1 sq. cm.	=	·1550 sq. in
1 cubic in.	=	16·387 c. cms.	1 cubic in.	=	·06102 c. cm.
1 grain	=	·064799 gramme	1 gm.	=	15·432 grains
1 ounce	=	28·3495 grammes	1 gm.	=	·035274 oz.
1 pound (7000 grs.)	=	453·59 gms.	1 gm.	=	·0022046 lb.

1 kilogramme or 1000 grammes = 2¼lbs. approx.

The gramme is the mass of a cubic centimetre (*i. e.* 1 millilitre) of water at a temperature of 4° C.

1 gallon of water occupies ·1604 cubic foot and weighs 10 lbs. at 62° F.

Centigrade and Fahrenheit Temperatures.

To convert temperatures in the Fahrenheit scale to the corresponding Centigrade temperature deduct 32° and take $\frac{5}{9}$ of the result.

To convert Centigrade to Fahrenheit multiply by $\frac{9}{5}$ and add 32°.

Circles and Spheres.

Let r = radius, and
d = diameter.

Circumference of a circle $= 2\pi r = \pi d$

Area " " $= \pi r^2 = \frac{\pi}{4} d^2 = \cdot 7854\, d^2$

Surface of a sphere $= 4\pi r^2 = \pi d^2$

Volume " " $= \frac{4}{3} \pi r^3 = \frac{\pi}{6} d^3$

Constants.

$\pi = 3\cdot 1415926536$ or $3\cdot 1416$ approx. or roughly $\frac{22}{7}$

$\pi^2 = 9\cdot 86965$; $\sqrt{\pi} = 1\cdot 77245$; $\frac{1}{\pi} = \cdot 31831$

Angle for which the arc is equal to the radius, 1 radian, $= 57\cdot 2958° = 3437\cdot 75' = 206265''$

Base of natural logarithms $= 2\cdot 7183$

To convert common to natural logarithms multiply by $2\cdot 3026$ and by $\cdot 4343$ to convert natural to common logarithms.

Weight of 1 lb. in London = 445,000 dynes.

1 foot-pound $= 1\cdot 3562 \times 10^7$ ergs.

1 horsepower = 33,000 foot lbs. per minute = 746 watts.

Value of the acceleration of gravity = 32·182 feet, or 981·17 cms. per second, *i. e.* the force of gravity = 981·17 dynes.

Heat Produced by a Current.

1 calorie = heat required to raise 1 gramme of water at 4° C. to 5° C.

Joule's equivalent $J = 42 \times 10^6$ ergs per calorie.

The heat H generated in a circuit of R ohms resistance by a current of C amperes in t seconds.

$$H = \cdot 24\, C^2 R t = \cdot 24\, E C t = \cdot 24\, \frac{E^2}{R}\, t$$

SECTION H.

STANDARD WIRE GAUGE.

No. S.W.G.	Diameter.		Area in square inches.	No. S.W.G.	Diameter.		Area in square inches.
	Mils. (·001 inch.)	Millimetres.			Mils. (·001 inch.)	Millimetres.	
7/0	500·	12·70	·1963	23	24·	·610	·000452
6/0	464·	11·78	·1691	24	22·	·559	·000380
5/0	432·	10·97	·1466	25	20·	·508	·000314
4/0	400·	10·16	·1257	26	18·	·457	·000254
3/0	372·	9·45	·1087	27	16·4	·417	·000211
2/0	348·	8·84	·0951	28	14·8	·376	·000172
0	324·	8·23	·0824	29	13·6	·345	·000145
1	300·	7·62	·0707	30	12·4	·315	·000121
2	276·	7·01	·0598	31	11·6	·295	·000106
3	252·	6·40	·0499	32	10·8	·274	·0000916
4	232·	5·89	·0423	33	10·0	·254	·0000785
5	212·	5·38	·0353	34	9·2	·234	·0000665
6	192·	4·88	·0290	35	8·4	·213	·0000554
7	176·	4·47	·0243	36	7·6	·193	·0000454
8	160·	4·06	·0201	37	6·8	·173	·0000363
9	144·	3·66	·0163	38	6·0	·152	·0000283
10	128·	3·25	·0129	39	5·2	·132	·0000212
11	116·	2·95	·0106	40	4·8	·122	·0000181
12	104·	2·64	·0085	41	4·4	·112	·0006152
13	92·	2·34	·00665	42	4·0	·102	·0000126
14	80·	2·03	·00503	43	3·6	·0914	·0000102
15	72·	1·83	·00407	44	3·2	·0813	·00000804
16	64·	1·63	·00322	45	2·8	·0711	·00000616
17	56·	1·42	·00246	46	2·4	·0610	·00000452
18	48·	1·22	·00181	47	2·0	·0508	·00000314
19	40·	1·016	·00126	48	1·6	·0406	·00000201
20	36·	·914	·00102	49	1·2	·0305	·00000113
21	32·	·813	·000804	50	1·0	·0254	·000000785
22	28·	·711	·000616				

SECTION I

SYLLABUSES OF EXAMINATIONS.

I.—Departmental Technical Examination for Assistant Superintendent or Superintendent (Telegraphs).

(P.O. circular No. 355 of 25th October, 1904.)

The subjects of examination are as follows :—

I. Crossing and looping wires with facility and certainty.
II. Tracing and localizing faults in instruments.
III. Tracing and localizing permanent and intermittent earth, contact and disconnection faults on wires.
IV. Methods of testing the electro-motive force and resistance of batteries, and a general knowledge of the essential features of the various description of batteries.
V. System of morning testing, with the necessary calculations in connection with the same.
VI. Making up special circuits in cases of emergency.
VII. Joining-up and adjusting single needle, single current, and double current Morse, both simplex and duplex, and Wheatstone apparatus.
VIII. Fitting a Wheatstone transmitter to an ordinary key worked circuit.
IX. A general knowledge of the principles of Quadruplex working.
X. Measuring resistances by the Wheatstone Bridge.
XI. A general knowledge of Telephone Switchboards and of trunk line working.

At Offices where there is an amalgamated staff for Postal and Telegraph work, Officers are required to pass the test before promotion to the rank of Assistant Superintendent (or of Superintendent where there is no Assistant Superintendent) if there are Telegraph duties proper to the class at the Office concerned. But in determining the standard of attainment required in these cases the nature of the Telegraph duties at the particular Office is taken into account.

All Officers who have attained the rank of Assistant Superintendent or Superintendent at any Office without passing the examination will be required to do so before promotion to higher Superintendentships.

II.—City and Guilds of London Institute.

Syllabus of Examinations in Telegraphy and Telephony.

The Examination will include questions founded on such subjects as the following:—

Ordinary Grade.

1. The fundamental principles of electricity in their application to the Electrical Engineering industries.
2. Units of Measurement. Standards of resistance, their practical construction and adjustment; electro-motive force and capacity; effects of temperature variation.
3. Galvanometers—principles and manufacture of—(*a*) absolute, (*b*) sensitive, (*c*) dead beat, (*d*) astatic, (*e*) differential. Shunts, ordinary and constant resistance.
4. Resistance coils—construction of; gauge and kind of wire; methods of winding and insulating.
5. Condensers—construction and testing of.
6. Induction coils—construction and principle of employment.
7. Call bells—magneto and battery bells; magneto generators and their construction.
8. Instruments necessary for the equipment of an electrical testing room—(*a*) for land telegraph lines, (*b*) for cables; methods of using the apparatus in the simpler forms of testing; apparatus required by linemen.
9. Electrical testing as applied to the inspection of apparatus and to the detection and removal of faults.

10. Faults in land and submarine lines; their nature, and the general principle of localization.

11. Essential qualities of iron and steel for temporary and permanent magnets respectively; methods of making permanent magnets; treatment of iron for electro-magnets; simple calculations as to the effective power of a permanent magnet or an electro-magnet.

12. The construction of telegraph and telephone lines, overhead and underground.

13. Metallic circuit system of working telephones and its advantages; inductive disturbances and methods of overcoming them; theory of such methods.

14. The construction of submarine cables, and the simpler of the phenomena connected with cables.

15. The simpler systems of telegraphy worked by hand, including the double current duplex.

16. Batteries used in telegraphy and telephony; principles, action, and construction; methods of grouping; universal battery working; application of secondary batteries to universal working.

17. The principles involved in the electrical transmission of sound and speech; the various systems of telephony and the instruments employed therein, including receivers, transmitters, call bells, and exchange switchboards.

18. Nature of and methods of preventing disturbances by earth currents.

19. Testing of materials employed in the construction of lines and apparatus.

20. Methods of protecting circuits and apparatus from lightning and from other extraneous heavy currents.

Honours Grade.

Candidates for Honours must have previously passed in the Ordinary Grade.

In the Honours Examination, which may be either in— I. Telegraphy, or II. Telephony, more difficult questions will be set in the subjects of the Ordinary Grade, and in addition a knowledge will be required of :—

SECTION I.—TELEGRAPHY.

1. The systems of high speed, quadruplex, multiplex,

and typeprinting telegraphs actually in use in Great Britain.

2. The manufacture, laying, testing, working, and repairing of submarine cables.

3. Practical methods for the supply of current, other than by primary batteries.

4. The commercial adaptability of the various systems of telegraphy.

5. Explanation of theory of the Wheatstone Bridge, tangent galvanometer, and reflecting galvanometer.

6. Repeaters—principles and construction; employment and adjustment; for single and double current, simplex and duplex, and high speed circuits.

7. Causes limiting the speed of automatic telegraph working, and methods of reducing their effect.

8. Daily and other periodical tests in theory and practice.

9. Wireless Telegraphy.

SECTION II.—TELEPHONY.

1. Transmitters and Receivers—various forms, construction and special features; adjustment; materials.

2. Translation from single wire to double wire systems and from circuit to circuit by means of condensers and of induction coils.

3. Methods of working telephones and telegraph instruments simultaneously on the same wire; theory of.

4. Conditions which limit the distance to which telephonic transmission is possible; use of iron and copper wires.

5. Individual calls for several stations on one circuit—theory and practical arrangement.

6. Exchange switchboard systems for single and for double wires. Multiple switches.

7. Switches, Intermediate, &c.

8. Automatic Call Boxes.

9. Hughes's Induction Balance.

It should be understood that generally the introduction of suitable illustrative diagrams in answers is to be desired.

INDEX

NOTES

1. All diagrams of connections are indexed under Connections.
2. Everything relating to Secondary cell working and the Universal Battery System is shewn under Universal Battery System.
3. All problems and numerical examples are indexed under Numerical Examples.

A

A and B wires, 793
A.B.C., 346
,, ,, action in sending, 349, 358
,, ,, bell, clockwork type, 350
,, ,, ,, , combined indicator and, 351
,, ,, ,, , switch, 352
,, ,, communicator generator form, 346, 352
,, ,, ,, old form, 355
,, ,, contact maker, 357
,, ,, current wave for one revolution, 354
,, ,, endless chain, 355
,, ,, escape wheel, 347
,, ,, generator, magnetic circuit of, 353
,, ,, ,, , theory of, 352
,, ,, indicator, 346
,, ,, ,, re-setting of, 350
,, ,, keys, 355
,, ,, leak working, 360
,, ,, pallet springs, 848
,, ,, pawl arm, 357
,, ,, , position of armature, 359
,, ,, , resistance of coils, 360, 361
,, ,, spur wheel, 357
,, ,, superimposed on telephone, 820
Absolute galvanometer, 87
Absorption, 651
Accidents, 708
Accumulator. *See* Secondary cells
Acids, definition of, 811
Acoustic dial or Neale's coils, 180
Adapters for iron poles, 700
Adjusting resistance for intermediate circuits, 502, 503
Aërial cables, 730
,, ,, , dry core, 731
,, ,, , suspenders, 731

Aërial cables suspending wire, 731

AËRIAL LINES :—
alterations to, 726
connected to underground, 794, 801
construction of, 656
diagram of section of, 729
diversions, 726
factor of safety of, 722
general principles, 727
on iron poles, 658
on railways, canals, roads, and private property, 656
renewals, 725
right angle turns, 729
surveying, 726
survey book, 727
use of interruption cable, 726
v. underground, 656, 657, 741
overhouse lines. *See* Overhouse
Agglomerate Leclanché, 26
,, 6-block, 27
Air. *See* Dry air
Air cap, 750, 787
,, ,, , closing of, 787
,, pump, 787
Air-space cable. *See* Cable
Amalgamation, 18
Ammeter, 461
Ampere, definition of, 12
,, hours, 44
,, turns, 76
Anion, 814
Anode, 814
A poles. *See* Poles
Apparatus and circuit resistance related, 76
Armature, 165, 174, 187, 189, 190, 191, 195, 199, 308, 346, 351, 353, 355 362, 363, 372, 404, 405, 418, 520, 537, 538, 543, 546
Armoured cable, 742
Arm bolts, 663
,, gauge, 663
Arms, Buller's iron, 700
,, , canting of, 667
,, , channel iron, 740
,, , double arming, 728
,, , earth-wiring of, 663
,, , extension, 726
,, , iron, 662, 737
,, , karri wood, 662
,, , oak, 662
,, , painting notches for, 663
,, , preservative process, 662
,, , sizes of, 662
,, , spacing of, 663
,, , wiring, 725

Arresters. *See* Lightning protectors
Artificial line, 823
Astatic needles, 99
Atom, 809
Atomic weight, 814
Auto relay, 522
,, switch, 509, 520
Automatic cut out, 482
,, system, definition of, 291
,, systems. *See* Wheatstone and Murray

B

Baker's fluid, 677
Battery coils, 237, 280, 324, 341, 493, 503, 506
Battery, definition of, 7
,, power, calculation of, 53
,, ,, , simplified rules, 627
,, resistance and speed of working, 513
,, symbol for, 44

BATTERIES :—

Cells, annual cost of maintenance, 42
,, , arrangement of, 43
,, , ,, ,, , choice of, 47
,, , ,, ,, , for efficiency, 48
,, , ,, ,, , for maximum power, 48
,, , ,, ,, , formula for best arrangement, 49
,, , capacity of, 44
,, , ,, , test for, 43
,, , characteristics of, 38
,, , difference of potential at poles of, 62
,, , elements positive and negative, 20, 812
,, , E.M.F. in multiple arc, 46
,, , ,, ,, parallel, 45
,, , ,, ,, series, 45
,, , first cost, 42
,, , ideal, characteristics, 41
,, , limits of E.M.F. and resistance, 40
,, , number to furnish a given current, 52
,, , poles and elements, 20, 812
,, , primary. *See* Dry cell, Bichromate, Daniell, Leclanché, Clark, and Sealed Standard
,, , purposes used for, 39, 40
,, , resistance in multiple arc, 46
,, , ,, ,, parallel, 45
,, , ,, ,, series, 44
,, , secondary. *See* Secondary cells
,, , simple voltaic, 18, 812
,, , size and E.M.F., 19
,, , ,, resistance, 74
,, , ,, E.M.F., resistance, and capacity, 43
,, , tabulated comparison of, 40
,, , voltaic, 18, 812
,, , wrongly connected, 49

Battery testing, 128
,, ,, , capacity of cells, 43
,, ,, , E.M.F. by direct deflection, 128
,, ,, ,, ,, , best conditions, 128
,, ,, E.M.F. equal current method, 131
,, ,, ,, ,, ,, , errors involved, 133
,, ,, ,, Potentiometer method, 135
,, ,, ,, Rayleigh's, 138
,, ,, ,, summary of methods, 142
,, ,, internal resistance, diminished deflection method, 146
,, ,, ,, ,, half ,, ,, ,, , 143
,, ,, ,, ,, Muirhead's method, 149
,, ,, ,, ,, Thomson's ,, 147
,, ,, ,, ,, Wheatstone bridge, 149
,, ,, ,, ,, secondary cells, 150
,, testing-board, 159
,, ,, ,, instrument, 150
,, ,, ,, ,, E.M.F. test, 151
,, ,, ,, ,, internal resistance test, 155
,, ,, ,, ,, percentage fall of E.M.F., 152
,, ,, ,, ,, shunts, 153
,, ,, ,, ,, winding of coils, 159
,, ,, ,, ,, Q and I detector, 654
B.A. unit, 13
B. Kick, 272
B.O.T. unit, 17
Bells, A.B.C., 350, 351
Bells, Bright's, 198
Bichromate cell, 28
,, ,, chemical action, 29
,, ,, defects to be avoided, 31
,, ,, secondary reactions, 31
,, ,, setting up, 30
,, ,, 3-pint size, 31
Binders for copper wire, 676
Blocks and ropes. *See* Tackle
Bobbin, length and diameter of wire to fill, 77
Boiler plate, 755
Bonding bolts and clips, 762
Boucherizing, 661
Boulton creosoting process, 660
Boxes. *See* Flush boxes and Buried boxes
Brackets, double horizontal, 735
,, vertical, 735
,, single, 735
Braziers, 786
Bridge duplex, 330
,, ,, , advantage of, 330
,, ,, , battery resistance coils, 336
,, ,, , compensation circuit, balancing, 336
,, ,, , double current, 334
,, ,, , ,, ,, , both keys at rest, 334
,, ,, , ,, ,, , intermediate position key, 336
,, ,, , ,, ,, , one key down, 335

Bridge duplex, effect of earth currents, 631
,, ,, , reading condenser, 337, 339
,, ,, , resistance of arms, 333
,, ,, , self-inductance of sending circuit, 341
,, ,, , signalling condensers, 337
,, ,, , ,, ,, , action of, 338
,, ,, , ,, ,, , summary of action of, 339
,, ,, , single current, intermediate position of key, 333
,, ,, , ,, ,, , principle, 331
Bridging coil, 285, 505, 507, 819
Britannia joint, 676
Bronze wire. *See* Wire
Bullers' bonding bolts and clips, 762
,, iron arms, 700, 738
,, ,, poles, 697
Buried boxes, 771

C

CABLE AIR SPACE AND PAPER CORE, 759
A and B wires, 793
aërial, 731
armoured, 742
capacity of, 768
compared, 760
composite, 770
conductor joints, 20 lb. and 40 lb., 785
,, ,, , 70 lb. and over, 784
,, ,, , spacing of, 786
corrosion of sheathing, 761
,, ,, ,, precautions, 761
desiccation of, 788
double solid plugs, 795
dry air, uses of, 787
drying of joint, 786
earthing of, in boxes, 762
,, ,, , in manholes, 757
insulation and dry air, 788
lay of, and colour of paper, 785
lead sheathing joint, 783
lengths of, 777
lubrication of, 782
multiple twin type, 771
numbering of, 793
overlap for jointing, 783
paper core cable, 760, 767
plugs double solid, 795
,, single solid, 794
pulling in, 777
,, ,, , motor winch, 780
,, ,, , into joint boxes, 782
,, ,, , choice of direction of, 783
,, ,, , lubrication, 782
quadruple pair type, 770
renewal of, 797

CABLE AIR SPACE AND PAPER CORE—*continued*
renewal of G.P. by, 796
,, ,, ,, ,, subsidiary drum method, 797
screened conductor, 760, 767, 796
,, ,, , details of, 768
serving offices *en route*, 795
sheathing, locating defects in, 788
single lead covered conductor type, 770
single solid joint, 794
solid joint, 794
speed of working on, 516
tail ending of, 797
testing of, 652
tests during construction, 790
,, for air-tight condition of cable, 788
,, ,, ,, ,, ,, joints, 787
,, ,, continuity of wires, 791
,, ,, correct jointing, 791
,, ,, dryness of joint, 786
,, ,, insulation of, 791
,, ,, ,, , maintenance tests, 791
,, ,, ,, , when very large number of wires, 791
,, ,, localizing defects in sheathing, 788
,, ,, numbering of wires, 793
,, ,, wiped joint, 787
twin types, 770
twisting in pairs, 766
v. G.P. cable, 760
variable lay, 767, 770, 771
,, ,, jointings of, 786
wiped joint, 787
worming pairs, 770
Cable bearer, 758
,, clip, 778
,, connection boxes, 574, 585, 792
,, ,, fixing of, 793
,, ,, gas plug for, 793
,, ,, gun metal linings, 792
,, distribution heads, 794
,, drums, 777
,, grip, 779
,, ,, protecting sleeve for, 779
,, G.P., cutting wires in and out, 775
,, ,, defective joints, 774
,, ,, jointing of, 772
,, ,, length pulled in, 772
,, ,, numbering of wires, 776
,, ,, pulling in of, 771, 772
,, ,, renewal of, 774
,, ,, replaced with dry core cable, 796
,, ,, ,, ,, ,, ,, ,, subsidiary drum method, 797
,, ,, spacing of joint boxes for, 772
,, G.P. *v.* air space cable, 760
,, head, 788

Cable paper core, 760, 767
,, ,, ,, capacity of, 768
,, racking grip, 782
,, screened conductor, 760, 767, 796
,, single conductor, lead covered, 770
,, supports, 756
Calcium chloride, 787
Canting of arms, 667
Capacity, 14, 211, 223, 248, 317, 338, 512, 515, 628, 639, 758, 768, 771, 853
,, and temperature, 75
,, effects of, on signals, 211, 317
,, , electrostatic unit of, 3
,, graphic representation of, and charge on line, 249
,, of air space cables, 761
,, ,, condensers, 211, 213, 214
,, ,, ,, in cascade or series, 216
,, ,, ,, ,, parallel, 215
,, ,, gutta-percha wires, 758
,, ,, paper core cables, 768
,, ,, plate condenser, 214
,, ,, screened conductor cables, 768
,, ,, various types of line, 515
,, , practical unit of, 14
,, , quantity and potential, 14
,, , specific inductive, 213
,, , ,, ,, of substances, 214
Caulking iron, 743
Cells, testing of. *See* Battery testing
Cement mortar, 747
Chambers, 700
Charging of line, time of, 258
Charring of pole butts, 659
Chatterton's compound, 773
Chemical compound, 810
,, symbols, 810
Chemistry, Notes on, 809
Chimney corner irons, 735
Choking coil, 822
Circuit, definition of, 11
,, earth, as return, 162
,, internal and external, 18
,, line and local, 208
,, loaded, 514
,, magnetic, 165
,, metallic, 630
,, silencer, 538
,, ,, details of valves, 540
Circuits, closed and open circuit working, 175
,, , compensation, 234
Circular brush, 747, 778
,, peg, 403
Clark cell, 12
,, ,, chemical action of, 35

Clark cell, E.M.F. of, 34
,, ,, use of, 126, 131, 134, 137, 138
Closed circuit working, 175
Coach screws, 696
Coils, battery, 237, 280, 324, 341, 493, 503, 506
,, , condenser, 108, 258, 502, 511
,, , duplex, 333, 397, 504
,, , electro-magnetic duplex, 397
,, induced needle, Neale's, 180
,, ,, ,, , necessity for, 177
,, ,, ,, , Spagnoletti's, 178
,, ,, ,, , Varley's, 177
,, , leak, 521, 529, 535
,, , resistance, 105
,, , ,, double winding of, 112
,, , ,, gauge of wire, 110
,, , ,, metal cased, 489, 506
,, , ,, temperature at which correct, 110
,, , ,, type of wire, 109
,, , ,, single plug type, 108
,, , retardation, 108, 258
,, , spark, 280
Combination duplex. *See* Single current sounder duplex
Combined resistance. *See* Joint resistance
Communicator, A.B.C., 346, 352, 355
Commutator, single needle, 176, 181
,, ,, ,, , early form, 202
,, used with D.P.S., 199
Compass, 4
Compensating resistance for shunts, 117
Compensation circuit, 234
Compo, 747
Compressor, 788
Concentrator, 402
,, , A.B.C. circuits, 403
,, , balancing resistances, 410
,, , battery power, 410
,, , circuits to be worked on, 403
,, , clearing signal, 408
,, , cords, 407
,, , general arrangement, 412
,, , indicators. *See* Indicator
,, , operation of, 407
,, , sounder circuits, single and double currents, 412
,, , time signal, 408, 410
Concrete, constituents of, 680
,, , uses of, 680, 747, 755
Condenser, 211
,, , dielectric, choice of, 217
,, discharge, 221
,, ,, , oscillatory, 221
,, ,, , time of, 257
,, for cutting off earth currents, 630
,, , insulation of, 220

Condenser, Mansbridge's method of manufacture, 217
,, , purposes for which used, 149, 249, 259, 260, 276, 282, 313, 316, 324, 327, 337, 426, 500, 503, 508, 510, 521, 530, 532, 535, 630, 815, 819, 821, 822, 825, 855, 856
,, shunted, 15, 313, 326, 500, 521
,, specification of insulation and capacity, 220
,, 7¼ m.f., 219
Condensers, joint capacity in cascade, 216
,, ,, ,, ,, parallel, 215
,, ,, ,, ,, series, 216
,, reading, 326
,, signalling, 325, 338, 823
Conductance, 55
Conductivity, 72
,, periodical test, 643
Conductor, 10
,, resistance tests, 641
,, ,, ,, periodical, 643
Conductors and temperature, 74
,, factors determining resistance of, 63
Conduits, 742
,, , cleaning and testing, 778

CONNECTIONS :—

A.B.C. *See* A.B.C.
Battery testing board, 160
,, ,, instrument, 153
Cells in multiple arc, 46
,, ,, parallel, 45
,, ,, series, 45
Concentrator, 407
,, double current sets, 409
,, single ,, ,, , 408
,, working sets, 408, 409
Diplex, receiving end, 289
,, , sending end, 288
Direct sounder, 171
,, ,, , 3-station circuit, 172
,, writer, 174
Double current sounder, 228
,, ,, ,, , duplex, 262
,, plate sounder, 200
Duplex. *See* Connections :—Single and Double current Sounder and Purves
E.M.F. test, equal current method, 132
,, ,, , potentiometer method, 136
,, ,, , Rayleigh compensation method, 138
Fuse, heat coil, and protector, 579
Galvanometer and shunt, 114
,, ,, universal shunt, 121
,, P.O. tangent, 90
Heat coil, fuse, and protector, 579
Hughes, duplex, 399
,, , simplex, 392

CONNECTIONS—*continued*
Insulation testing set, 649
Intercommunication system, circuit normal, 418
,, ,, , ,, through, 419
,, ,, , engaged test, 423
,, ,, , Purves' duplex, 426
Internal resistance test, Kempe's method, 149
,, ,, ,, , Muirhead's method, 149
,, ,, ,, , Thomson's, 147
Key, double current, 226
,, single ,, with switch, 495
,, ,, ,, 6-terminal, 409
,, 6-terminal reversing, 493, 506
Keys in quadruplex working, 506
Localizing contacts, 613
,, disconnections, 611
,, earths, 610
Morning test, skeleton connections of various tests, 603
,, ,, , switch tablet, 602
Murray loop test, 646
Purves' duplex, 426
Quadruplex A side relayed, 542, 544
,, condenser B side, 277, 853
,, relaying sounder B side, 275
,, repeater, 549
,, skeleton diagram, 268
,, superimposing,
,, up station, 282, 855
Relay P.O. Standard A, 193
Repeater, Bridge on cable side, 532
,, , duplex, principle, 527
,, ,, , leak circuit, 530
,, , forked, 535
,, , quadruplex, 549
,, , simplex, 521
,, , test box connections, 541
Resistance box, 106
Rheostat "C," 112
Shunt and galvo, 114
,, universal, 121
Single current sounder, 207
,, ,, ,, duplex, combination, 237
,, ,, ,, full connections, 242
,, ,, ,, opposition, 233
Sounder. *See* Double current ; Single current
Sounder silencer, 538
Steljes, leak working, 369
,, , series working, 368
Test box, changes at, 553
,, ,, detector, 617
,, ,, double current sounder, 552
,, ,, , switch spring type, 562
,, ,, U-link type, 559
,, ,, , test tablet 7-hole, 618
,, ,, ,, ,, , 22-hole, 619

CONNECTIONS—*continued*
Universal Battery System :—
Double plate sounder, 490
Double current sounder duplex, 499
,, ,, ,, ,, principle, 498
,, ,, ,, ,, Bridge method, 504
,, ,, ,, ,, intermediate offices, 497
,, ,, ,, ,, up and down offices, 496
Keys for quadruplex working, 506
Quadruplex, 508, 856
,, , Wheatstone on A side, 510
Single current sounder duplex, 494
,, ,, ,, up and down offices, 492
,, ,, ,, intermediate offices, 493
Single Needle commutator, 487
,, ,, up, down and intermediate offices, 488
Switch quadruplex and single, 507, 854
Test box speaking set, 511
Wheatstone, Bridge duplex, 504
,, duplex, 503
,, intermediate working, 501
,, transmitter, 500
,, up office, 500
Varley loop test, 644
Wheatstone A.B.C. series working, 360
,, ,, leak working, 361
Wheatstone Bridge, 636
,, ,, , Murray test, 646
,, ,, , Pomeroy test, 647
,, ,, , Varley test, 644
,, duplex set, 324
,, ,, switch, 323
,, ,, , Bridge method, 340
,, ,, improved differential, 327
,, receiver, 312
,, simplex set, 321
,, transmitter, 320

Connecting link, 780
Constant, 122, 126
,, , insulation testing set, 649
,, , tangent galvanometer, 122, 124
Construction of aërial lines, 656
,, ,, overhouse lines, 732
,, ,, underground lines, 741
Contact, localization test for, 612
,, , loop test for position of, 647
Container, 788
Controlling magnet, 88, 92, 125
Convolutions of wire on galvanometers and relays, 76, 92
Copper, Matthiessen's standard for, *footnote* 68
,, taping of cable cores, 768
,, wire. *See* Wire
Cordeaux insulator, 666

Cords, 407
Cost of batteries, 41, 42
,, ,, iron poles, 658
,, ,, open *v.* covered wires, 656, 741
Coulomb, 14, 211
,, meter, 102
Covered wire fault, 615
Crane grease, 761
Creosote, quantity injected, 660
Creosoting process, 659
Cross-connection frames, 574, 585
,, ,, strips, 561
,, ,, wires, 586
Crosses, 556, 559, 624
Crossing wires, 556, 624
Curbing, 318
Current, absolute determination of, 87
,, , deflection of compass needle by, 83
,, , direction of, 10
,, , eddy currents, 97
,, , effects of, 7, 81
,, , measurement of, 81, 119, 461
,, to work. *See* under the particular type of instrument

D

Daniell battery, 12, 20
,, ,, chemical action, 22
,, ,, E.M.F. and internal resistance, 40
,, ,, large and small, 24
,, ,, setting up, 23
,, ,, size of plates, 21
,, ,, use of, 40, 173, 174, 206, 209, 230, 245, 266, 288, 345 410, 541, 605, 617, 637
,, ,, use of water, sulphuric acid, and zinc sulphate 22
,, standard cell, 37
Dead beat galvanometer, 97
Deafeners. *See* Silencers
Decay of timber, 659
Deck troughing, 758
Deflection of magnetic needle, rules, 10
Demagnetization, conditions for, 166, 189, 197
Derricking poles, 705
Desiccator, 787
Detector Q and I, 654, 775
,, ,, figure of merit of, 654
,, ,, resistance of, 654
,, , test box, 617
,, , ,, ,, , C type, 618
Dial, Neale's acoustic, 180
Dielectric, 211
,, polarization, 651
,, strength, 759

Difference of potential, 2
,, ,, ,, at poles of cells, 62
Differential duplex. *See* Duplex
,, galvanometer, 235
,, ,, uses of, 242, 262, 282, 321, 324, 327, 340, 399, 494, 499, 500, 501, 503, 504, 508, 510, 511, 521, 531, 533, 542, 544, 549, 561, 618, 619, 821, 822, 824, 855, 856
,, winding, 91
,, ,, test for, 197
Dip. *See* Sag
Diplex, 288
Direct sounder, 171
,, ,, battery power, 173
,, ,, current required, 173
,, ,, duplex, 235
,, ,, intermediate stations, 172
,, ,, *v.* single current sounder, 209
,, writer, duplex, 244
Discharger, 541
Disconnection, localizing, 611
Disruptive discharge, 211
Distribution of current in divided circuits, 58

DOUBLE CURRENT SOUNDER:—
battery power, 230
converted to work single current, 229
current required, 230
faults, 229
path of current, 229
principle, 222
duplex, 245
,, aids to memorizing connections, 261
,, arrangement of compensation circuit, 256, 258
,, battery power for, 266
,, both keys at rest, 247
,, capacity balance, effects if defective, 258
,, ,, ,, , relative values both ends, 260
,, ,, ,, , practical adjustment of, 264
,, ,, effect on working, 248
,, condenser and line discharges, path of, 252
,, summary of ditto, 256
,, conditions required for duplex working, 246
,, effect of loss on line, 266
,, faults, 265
,, one key depressed, 248
,, resistance balance, 262
Double current system, 222
,, ,, ,, advantages of, 222, 225
,, ,, ,, effect of reverse current on charge on line, 223
Double plate sounder, 198
,, ,, ,, adjustment, 203
,, ,, ,, arrangement of apparatus, 203
,, ,, ,, faults, 205
,, ,, ,, path of current, 201

Double plate sounder, plate sounders, 199
,, ,, ,, ,, ,, , figure of merit, 206
,, ,, ,, ,, ,, , resistance, 202
Double split, 237
, sulphation theory, 432
,, winding of resistance coils, 112
Down station, 170
Draw tongs, 710, 726
,, vices, 710
,, wire, 744, 777
Drop indicator, 405
Drum barrow, 709
Dry air plant, 787
,, ,, ,, motor driven, 788
,, ,, ,, uses of, 787
,, battery 2-cell, 775
,, ,, 10-cell and resistance coil, 41
,, cells, 31
,, ,, E.C.C., 32
,, ,, Gassner, 32
,, ,, Hellesen, 33
,, ,, Obach, 33
,, ,, uses, 40, 599, 648
,, core cable. *See* Cable air space and paper core
,, joints, 643
,, rot, 659
Ductility, 669, 671, 672, 673
Duct routes, 746
Ducts, 742
,, , multiple way, 749
,, , spacing of joints, 748
,, *v.* pipes, 746
Duplex. *See* Bridge duplex, Parves duplex, direct writer duplex, single current duplex, double current duplex, Hughes duplex, Wheatstone
,, differential, opposition method, 232
,, ,, , ,, ,, intermediate position of key, 234
,, ,, , ,, ,, use of non-polarized relay, 235
,, resistance coils, 325, 505
,, electro-magnetic coils, 397
Dyne, 3

E

Earth as return path, 162
,, clip, 164
,, connection, 164
,, currents, 628
,, ,, , bridge *v.* differential duplex, 631
,, ,, , elimination of, in testing, 640, 641
,, ,, , remedies, 630, 631
,, faults, localizing, 610
,, plate, 164
,, test for position of, 644, 645
Earthing of cables in manholes, 757

Earth connection for protectors, 573
,, fault, Murray ,, ,, , 645
,, ,, , Varley test for, 644
,, resistance of, 164
,, test for resistance of, 647
,, wire as lightning conductor, 678
,, wiring, 677
,, ,, of arms, 663
,, ,, poles on viaducts, 678
,, ,, use of copper wire, 678
Earth's magnetic field, 82
Ebonite, 664
Eden, 151, 587

EDEN MORNING TEST:—
advantages of, 588
conversion of readings, 600
fault at centre of circuit, 594
localization tests with tangent, 605
perfect current, 595
position of a fault, 602
practical arrangements, 597
principle, 587
received current, 595
resistance of fault, 597
routine of test, 601
sent current, 595
single wires, 605
value of testing E.M.F., 597
verification of battery E.M.F., 599
E.C.C. dry cell, 32
Eddy currents, 97, 174
Electricity, 1
,, , dynamic, 7
,, , positive and negative, 1
,, , static, 1
,, , voltaic, 7
Electrification, 651, 768
Electrode, 814
Electrolyte 814
Electrolytic damage to cables, 761
Electromagnet, 75, 164
,, ,, , demagnetization of, 167, 197
,, ,, , figure of merit and resistance, 77
Electromagnetic bridging coils, 397
,, cut out, 483
,, effects of current, 7
,, induction, 352
,, inertia. *See* Self-induction
,, leak, 398
Electromotive force, 11
E.M.F. of Clark cell, 34
,, definition of, 11
,, unit of, 11
Electrons, *footnote* 7, 814

Electro-static capacity. *See* Capacity
Electro-static induction. *See* Induction
,, ,, lines of force, 212
Element, 810
Elements and poles, 20, 812
,, positive and negative, 20, 812
Engaged test, 422
E.P.S. secondary cell, 441
Equalizing resistance for intermediate workings, 488
Erg, 3
Ewing, 804
Examination syllabuses, 865
Extension arms, 726
Extra current. *See* Self-induction
Eye spike, 740

F

Factor of safety and sag of wire, 709
,, ,, ,, of open lines, 722
False zero, 641
Farad, definition of, 14
Farady, 769
Fast repeater. *See* Repeater
Fault at centre of circuit, 594
Faults, arrangements for removal of, 608
,, , causes of line faults, 619
,, , covered wire faults, 615
,, , in apparatus, 186, 205, 208, 229, 243, 265, 286
,, , localization tests for contacts, 612
,, ,, ,, ,, disconnections, 611
,, ,, ,, ,, earths, 610
,, ,, ,, ,, intermittent faults, 614
,, ,, ,, ,, with tangent, 605
,, , Murray test for position of, 645
,, , necessity for earth connection when localizing contacts, 612
,, on dry core cables, 798
,, , various types of, 609
,, , Varley test for position, of, 644
Faulty circuits, making good of, 623, 624
Figure of merit, 104
,, ,, ,, and resistance of galvo or electromagnet, 77
,, ,, ,, of differential galvo, 236
,, ,, ,, ,, direct writer, 175
,, ,, ,, ,, galvanometers, 104, 105
,, ,, ,, ,, local inker, 210
,, ,, ,, ,, needle coils, 179
,, ,, ,, ,, plate sounders, 206
,, ,, ,, ,, relaying sounder, 188
,, ,, ,, ,, Siemen's relay, 197
,, ,, ,, ,, single current galvo, 206
,, ,, ,, ,, sounders, 168
,, ,, ,, ,, standard relay A, 195
,, ,, ,, ,, ,, ,, B, 195
Finials for poles, 662, 802
Fir, 658, 662

Fire pots on roofs, 733
,, precautions against, 583
,, -proof chamber, 584
Fitzgerald, 434
Float for transport of cables, 778
Fluids, depolarizing and exciting, 20
Flush boxes, dimensions of, 751
,, ,, , extra large, 752
Force, definition of, 3
,, of attraction between charged bodies, 3
,, ,, ,, ,, magnetic poles, 6
,, , unit of, 3
Forces, parallelogram of, 720
,, , triangle of, 718
Forked repeater, 534
Forking wires, 556
Fuse insulator, 580
Fuses, 464, 466, 474, 489, 570, 576, 800
,, , position for protection from power circuits, 581
Fuller's mercury bichromate, 28

G

Galvanometer, 81
,, , absolute, 87
,, , astatic, 99
,, , ballistic, 102
,, , constant of, 122, 126
,, , controlling magnet, 88, 92, 125
,, , D'Arsonval, 100
,, , ,, , advantages of, 102
,, , ,, , damping of, 102
,, , ,, , pointer type, 102
,, , dead beat, 97
,, , differential, 235, 242, 262, 282, 321, 324, 326, 327, 340, 399, 494, 499, 500, 501, 503, 504, 508, 510, 511, 521, 531, 533, 542, 544, 549, 561, 618, 619, 821, 822, 824, 855, 856
,, , differential winding of, 91
,, , figure of merit. *See* Figure of merit
,, , Gaugain or Helmholtz, 84, 85
,, , horizontal, 93, 636, 648
,, , Kelvin, high grade, 98
,, , ,, mica vane for damping, 99
,, , ,, original form, 95
,, , ,, scissors magnet control, 99
,, , ,, simple form, 98
,, , parallax error, 89, 94
,, , P.O. tangent, 88, 118, 597
,, , ,, ,, , angle of maximum sensitiveness, 119
,, , ,, ,, , connections of, 90
,, , ,, ,, , constant of, 122
,, , ,, ,, , ,, , verified, 123
,, , ,, ,, , dimensions of, 88
,, , ,, ,, , number of convolutions, 91

Galvanometer, P.O. tangent, resistance of coils, 91
,, , ,, ,, , short circuiting key, 89, 91
,, , Q and I detector, 654
,, , reflecting, 94
,, , ,, , constant of, 126
,, , ,, , correction of deflection, 96
,, , ,, , damping of, 96
,, , ,, , lamp and scale, 97
,, , ,, , principle of, 95
,, , sensitiveness, 104
,, , single current, 169, 171, 200, 228, 408, 409, 490, 492, 493, 496
,, , ,, ,, , resistance of, 170
,, , ,, ,, , 900ω, 423
,, , skew scale, 90
,, , tangent, 84
,, , ,, , corrections, 84
,, , ,, , diameter of coil, 92
,, , ,, , essential features of, 84
,, , ,, , method of dividing the scale, 86
,, , ,, , number of convolutions, 92
,, , ,, , scale, 85
,, , ,, , sensitiveness and resistance, 93
,, shunt. *See* Shunt
,, , Thompson. *See* Galvanometer, Kelvin
Galvanizing, 671
Game guards, 730
Gas battery, 428
,, pipe and earth connection, 164
,, plug, 788
Gassner dry cell, 32
Gauging disc for C.I. pipes, 743
Generator, 346, 352
German silver, 109
Gladstone and Tribe, 432
Glass for insulators, 664
,, tube fuse. *See* Fuse
Godfroy's electromagnetic leak, 400
Graduator, 815
Guards, hook, 696
,, , stay, 687
Gutta percha. *See* Wire
,, ,, effect of pressure, 75
,, ,, ,, ,, temperature changes, 75

H

Hard drawn copper. *See* Wire
Hardie, 515
H-armature, 353
Hart secondary cell, 443
Heat coil, 513, 574, 577
,, ,, A type, 577
,, ,, B ,, 578
,, ,, and protector strip, 582

Heat coils and fuses, principle governing fittings of, 580
,, ,, , protectors D, and fuses, 579
Heaviside, Oliver, 514, 515
Hellesen dry cell, 33
Henry, 16
Hole-digging for poles, 680
Hook guards, 696
Horizontal galvanometer, 93, 636, 648
Horsepower and watts, 17

HUGHES' APPARATUS :—
adjustment of, 395
armature released, 386
,, replaced, 378, 388
change over letters and figures, 384
characters, order of, 385
chariot, 371, 378
conventional signals, 394
correcting cam, 388
,, for synchronism, 388
,, wheel, 383
detent, 390
disconnection of magnet coils, 377, 388
duplex, 397
,, balancing, 401
,, resistance coils, 397
,, signalling condensers, 397
earthing of line, 376
electromagnet, 372
,, , adjustment of, 374
,, , resistance of coils, 374
electromagnetic duplex coils, 397
,, leak, 398
figure blank key, 378
governor, 376
keyboard, 371, 378
letter blank key, 378
manipulation, 393
motive power, 376
number of characters printed per revolution, 382
night bell, 393
paper movement, 389
,, moving cam, 388
pin plate, 381
preparations before connection to line, 394
principle, 370
printing axle cams, 388
,, ,, entrained, 387
,, cam, 388
rejector, 380
retardation, effects of, 396
speed of working, 370, 396
switch, 391
typewheel axle, 383
zero adjusting lever, 390

Humming of wires, 733
Humming of wires, solid *v.* stranded wires, 732, 735
Hydrometer, 433

I

Impedance, 567
Impurities in zinc, 18
Incrementer, 546
Increment key. *See* Keys
,, system. *See* Quadruplex
India-rubber, 759
Indicator A.B.C., 346, 351
Indicator, drop indicator, 405
,, key, 418
,, non-polarized drop, 540
,, relays. *See* Relays
Induced needles. *See* Coils
Inductance. *See* Self-inductance
,, coils, 514
,, ,, for protector, 570
,, spiral ,, ,, , 573
Induction, dynamic or electromagnetic, 352, 764, 769
,, , electro static, 2, 763
,, , magnetic, 5
,, , parallel circuits, 765
Inductive capacity. *See* Capacity
,, disturbances, 763, 769
Inker, direct, 173
,, , local, 210
Insulating compound, 795
Insulation resistance, 588
apparent and true, 589
and equivalent fault, 591
and speed of working, 607
dry core cables, 652, 791
,, ,, ,, grouping of wires, 652
,, ,, ,, testing of, 652, 790
G.P. wire, new, 759
,, ,, , minimum value, 759
open wires, maintenance standard, 607
,, ,, , working ,, , 607
total and per mileage values, 592
,, of extended circuits, 593
testing set, 648

Insulators, 10
and changes of pressure, 75
,, ,, ,, temperature, 75
bolts for, 665
brown, 664
canting of, 695
cleansing of, 666
Cordeaux, 666
design of, 665
double shed brown, 664
,, ,, white, 666

INSULATORS—*continued*
ebonite, 664
fixed bolt, 665
for secondary cells, 451
glass, 664
Langdon, 667
material chosen for, 664
medium size, 669
P.O. terminal, 667
shackle type, 667
side knob, 667
spindles, 665, 667
,, , addition of washer, 667
,, , terminal *v.* J-bolts, 668
Intensity of magnetization, 6
Intercommunication system. *See* London Metropolitan Switching system
Interference due to leakage from power circuits, 628
Intermediate returns, 565
,, stations, 172
Intermittent faults, 614
Interruption cable, 726, 731, 797
Ions, 813
Iron poles, 658, 697
,, resistivity of, 68
,, wire. *See* Wire
Isochronism, 826

J

Jack. *See* Switch spring
J-bolts, 667
,, $\frac{3}{4}$" & $\frac{5}{8}$", 668
Jockey wheel, 302
Joint box, 751
,, capacity, 215
,, markers, 750
,, resistance, 55
,, testing, 787
Jointing. *See* Wire and Cable
,, sleeves, copper, 784
Joists, rolled steel, 740, 755
Jumper wires, 586

K

Karri wood, 662
Kathode, 814
Kation, 814
Kelvin, 98
Key, A Key, 278
,, , B Key, 268, 278
,, , double current, 225, 262, 289, 321, 324, 327, 340, 426, 497, 500, 501, 503, 506, 508, 510, 511, 824, 855, 856
,, , for forked repeaters, 536
,, , increment, 268, 278
,, , indicator key, 418
,, , reversing, 268, 278

Key, single current, 169, 174, 207, 233, 242, 399, 408, 492, 542, 544, 816, 821
,, ,, ,, 6-terminal, 412
,, ,, ,, with switch, 495, 499, 500, 521, 530, 542, 544, 824
,, ,, 6-terminal reversings, 280, 493, 506, 508, 510, 544, 824, 855, 856
Keys, single needle. *See* Commutator
Keystone connecting link, 780
Kick, B Kick. *See* Quadruplex
,, on C.B. duplex, 427
King, 441
Kirchoff's laws, 58
K.R., 512

L

La Cour wheel, 838
Ladder fittings, 704
Lamp indicator, 414
Lay, in dry core cables, 767
Lead cable. *See* Cable
,, hydrated peroxide, 434
,, monoxide, 432
,, peroxide, 429
,, spongy lead, 429
,, sulphate, 429
,, ,, ,, conductivity of, 433
Leading in, 667
,, ,, cup, 803
Leak circuit, duplex repeater, 529
,, coils, repeater, 523
Leaks, distributed, 514
Leak switch, duplex repeater, 529
,, working, 360, 369
Leclanché cell, 24
,, agglomerate, 26
,, chemical action of, 27
,, 6-block agglomerate, 27
,, sizes of, 26
,, use of, 40, 185, 206, 327,
Lifting Jacks, 778
Lightning, 566
,, conductor, 678

LIGHTNING PROTECTORS:—
A & B, 567
C, 568, 800
D, 569
earth for, 573
earthing of cases, 574
in pole test boxes, 800
Lodge, 571
position of, 573
principle of, 566
reel, 567
Saunders, 571
tablet, 570
triple disc for, 569

LIGHTNING PROTECTORS—*continued*
use of inductance spiral, 573, 800
vacuum, 570, 800
Line and local circuit, 198, 208
,, construction. *See* Aërial, overhouse, and underground
,, faults. *See* Faults
,, ,, causes of, 619
,, stays, 728
,, wire. *See* Wire
Lines, capacity and resistance of, 515
,, of force, 4, 764, 769
,, ,, ,, electro static, 212
Litharge, 432
Loaded circuits, 514
Local action, 18
,, battery, 198, 208
Localization tests, 608
Lodestone, 4
Lodge, Sir Oliver J., 515, 571
LONDON METROPOLITAN SWITCHING SYSTEM, 402, 412
adjustment of translating relays, 425
calling by key, 415
,, lamp, 415, 419
clearing ,, 414
,, signal, 421
collecting offices, 422
cut off relay, 422
direct circuits, 413
double current working, 421
engaged indicator, 422
,, test, 414, 422
home section, 413, 414
indicator key, 414, 415, 418
,, ,, released, 420, 424
intermediate offices, 423
lamp indicator, 414
line relay, 419
method of indicating when circuit is disengaged, 452
,, ,, operating, 414
modifications for provincial use, 424
multiple switch, 413
night bell, 425
number of circuits, 412
permanent current, 419
pilot lamp, 425
polarized sounder, 416
Purves duplex, 425
,, ,, night arrangement, 427
simultaneous depression of two speaking keys, 425
single current working, 421
speaking key, 414, 420
standard resistance of lines, 424
time signalled, 425
translating relays, 420, 421
two circuits connected, 420

London Metropolitan Switching System, voltages used, 418, 419
Longitudinal stays, 728
Looping mains, 478, 630
,, of wires, 555
Loop test for position of fault. *See* Faults

M

Magnet, moment of, 7
,, , permanent, 4
Magnetic circuit, 164
,, ,, , law of, 76
,, ,, of sounder, 165
,, effect of current, 7, 8
,, field, 6, 83
,, ,, , unit of, 6
,, meridian, 95
,, moment, 7
,, pole, unit, 6
,, saturation, 804
,, storms, 629
Magnetism, 4
,, , earth's, 4
,, , molecular theory of, 804
Magnetization, intensity of, 804
,, , saturation, 804
,, , three stages of, 807
Magnetizing force of solenoid, 76
,, steel, 6
Magneto bells, 351
,, electric machine. *See* Generator
,, motive force, 76
Making good of faulty circuits. *See* Faulty circuits
,, up of special circuits. *See* Special circuits
Mandrels, 746, 778
Manganese dioxide, 25
,, , pebble, 25
Manganin, 109
Manholes, footway types, 755
,, , mud excluder for, 758
,, , roadway types, 757
Mansbridge G. F., 217
Marine glue, 20
Mariner's compass, 4
Markers for Joints, 750
Marking current, 222
Matthiessen's standard for copper wires, *footnote* 68
Mechanical tests of iron and copper wires, 671–674
Megohm, 12
Metallic circuit, 555, 630, 823
,, ,, , speed of, 517
,, ,, , working, 555, 630
Metzger, 431
Mho, 56
Microfarad, 15

Microhm, 12
Milliampere, 12
Minium, 432
Mirror galvanometer. *See* Galvanometer
Molecular theory of magnetism, 804
Molecule, 809
Moment of a magnet, 7
Morning test. *See* Eden
Morse sounder. *See* Sounder
Motor generator, 482
,, pump, 787
Muirhead's battery test, 149
Multiple, 413
Multiplying power of shunt, 114, 122
Murray alphabet, 826
,, capacity of system, 852
,, correction of errors, 830
,, distributor, 838
,, figure and letter shift, 828
,, La Cour wheel, 838
,, method of securing isochronism, 840
,, printer, 844
,, reed, 838
,, system, 826
,, tape, 828
,, transmitter, 834
,, ,, bias adjustment, 837
,, typewriters keyboard perforator, 832
,, unison diagram, 846

N

Neale's coils, 180
Needle, deflection of, 9, 10
,, system. *See* Single needle
Negative electricity, 1
,, plate and pole, 20, 812
News circuits, 326
Noise from open wires, 732, 733
Non-polarized relay. *See* Relays
N-pole of solenoid, 165
Null method, definition, 135
Numbering of poles, 730
,, wires, 776

NUMERICAL EXAMPLES:—
Aërial line, factor of safety, 723
Area and diameter of round wires, 65
Battery. *See* Cells
Board of Trade unit, 17
Bridge duplex, battery power, 345
,, ,, , currents, 341
,, ,, , rheostat resistance, 345
Capacity of aërial lines, 858
,, ,, G.P. wires, 859
,, ,, ,, ,, compared with paper core cable wires, 859

NUMERICAL EXAMPLES—*continued*
Capacity, quantity, and potential, 14, 15
,, , relative, of two cable cores, 860
,, , required thickness of dielectric, 861
Cells, best arrangement of, for electro-magnet, 79
,, , difference of potential, open and closed circuit, 62
,, , internal resistance from ditto (two methods of working), 63
,, , E.M.F. and resistance of, in multiple arc, 46
,, , ,, ,, ,, ,, , ,, parallel, 46
,, , ,, ,, ,, ,, , ,, series, 45
,, , ,, ,, ,, ,, , ,, ,, , certain cells reversed, 50
,, , of unequal sizes in parallel, 50
,, , ,, ,, E.M.F.'s in parallel, 51
,, , number and arrangement to furnish a large current, 54
,, , ,, in series required to furnish a given current, 52
,, , ,, required to work a given circuit, 53
,, , secondary, number required to furnish a given current, 51
Conductivity, percentage, of copper, 72
Conductor resistance and temperature, 74
Current, division of, several paths in parallel, 58
,, , ,, , two paths in parallel, 59
,, , in circuit consisting of a battery and resistance, 61
,, , in each of several paths in parallel due to cells in multiple arc, 61
,, , in each part of a duplex, 239
,, required to work a relay rewound to a given resistance, 79
Diameter of wires, 66, 73
Duplex, current in each part of, 239
Eden morning test, 596, 599, 604, 606
Electromagnet, best arrangement of cells to energize it, 79
,, magnetic effects with coils in series and parallel, 77
,, ditto, economy of battery power considered, 78
,, rewinding, 79
E.M.F. measured by battery testing instrument, 152, 153
,, ,, ,, direct deflection method, 130
,, ,, ,, equal current method, 133
,, ,, ,, potential divider, 141
,, ,, ,, potentiometer, 137
,, ,, ,, Rayleigh method, 139
,, ,, ,, Wiedemann method, 135
Fault at centre of circuit, 593
,, , Eden test for position of, 604
Figure of merit and diameter of wire on electromagnet, 79
Galvanometer shunt. *See* Shunts
Insulation of extended circuits, 593
,, of loop morning test, 599
,, , thickness of, 861
Internal res. measured by battery testing inst., proof of principle, 156
,, ,, ,, ,, ,, ,, ,, , shunt and resistance of battery, 158
,, ,, ,, ,, diminished deflection method, 146
,, ,, ,, ,, half deflection method, 144
,, ,, ,, ,, Muirhead method, 150
,, ,, ,, ,, Thomson method, 148
,, ,, of secondary cells, 151

NUMERICAL EXAMPLES—*continued*
Joint resistance of galvanometer and shunt, 117
,, ,, ,, several paths in multiple arc, 58
,, ,, ,, ,, ,, in parallel, 56
,, ,, ,, ,, ,, of equal resistance in parallel, 56
,, ,, ,, two paths in parallel, 57
Length of wires and resistance, 65, 66
Magnet, force exerted on isolated pole, 7
Mho and ohm, 56
Murray loop test, 646
Ohm's law, 13
Ohm and mho, 56
Perfect current, 595
Pole, breaking stress, 724
,, , downward thrust on, 718
,, , factor of safety on, 724
,, , horizontal stress on, 720, 723, 724
Potential, quantity and capacity, 14, 15
Quadruplex, currents, 269
Quantity, potential and capacity, 14, 15
Received current, 595
Resistance and area of wires, 65
,, ,, length of wires of equal diameter, 64
,, ,, ,, ,, ,, ,, ,, weight, 70
,, length and area of wires, 65
,, ,, ,, weight of wires, 70, 71
,, length, area, and diameter of wires, 65, 67
,, of a path in parallel knowing resistance of the other path and currents in each, 60
,, of a path in parallel knowing resistance of the other path and currents in each, another method, 60
,, of a path in parallel with another of known resistance given joint resistance, 57
,, of relay to work a given line, 80
,, of a wire given dimension and resistance of a foot grain, 72
,, ,, ,, ,, ,, ,, resistivity, 69
,, ,, ,, ,, weight of ohm-mile, 72
,, , weight, and diameter of wires, 73
Resistances in series, 55
Resistivities, comparison of, 69
Resistivity of a material, 69
Secondary cells, charging current, 480
Sent current, 595
Shunt, constant of shunted galvo, 116, 120
,, , multiplying power of, 116
,, , resistance of, 116, 119
Speed of working, 516, 860
Stay, necessity for, at angle, 724
Stays, stress on, at a terminal pole, 718
,, , ,, ,, , due to angle, 720
,, , ,, ,, , factor of safety on, 718, 719, 722
,, , ,, ,, , parallel stays, 718
Wheatstone bridge, individual resistance of bunched wires, 641
,, ,, , principle of, 632

O

Oak for arms, 662
Obach dry cell, 33
Ohm, definition of, 11
Ohm-mile of iron and copper, 71, 627
Ohm's law, 13
Open and closed circuit working, 175
Outrigger. (*See* also pole-spur), 692
Overhouse line wire, 732
,, lines, 657, 732
,, ,, humming of wires, 732, 733
Ozokerite tape, 758

P

Painted poles, 659, 661
Paper for perforator, 292
,, sleeves, 784
,, ,, , drying of, 786
Parallelogram of forces, 720
Pegs, 403, 406, 419
,, , double test pegs, 585
,, and cords for test boards, 564
Peg switch, 529
Percentage conductivity, 72
Perforator. *See* Murray and Wheatstone automatic system
Permanent current, 419
,, magnet, 4
Permeability, 76
Peroxide of lead, 429
Petroleum jelly, 761, 782
Phonic wheel, 838
Pillar test boxes, 750, 792
Pin connectors, 790
Pipe line, cost of, 746
Pipes C.I., 742
,, ,, bell-mouth, 745, 753
,, ,, bonding together of, 761, 762
,, ,, draw wire, 744
,, ,, jointing of, 743
,, ,, joints spaced, 744
,, ,, sizes of, 743
,, ,, slide, 749
,, ,, Smith's composition, 742
,, ,, solid bends, 745
,, ,, split, 750
,, ,, terminating, 752
Pit channels, 753
Pitch pine, 658
Plans, symbols used upon, 623
Planté, 429
Plate protector, 570
Platinoid, 109
Platinum, 169, 576
,, silver, 109

Plus circuit, 823
Pneumatic perforator, 298
Polarization, 19
,, errors due to, in testing, 149
Polarized relays. *See* Relays
,, sounder, 416
Pole-changer, 543
,, cart, 704
,, chairs, 737
,, ,, , rectangular, 740
,, climbers, 709
,, fittings, spacing of, 663
,, holes, 680
,, lifters, 705
,, roof, 661, 695
,, spur, 690
,, steps, 696
,, test box, 570, 799, 800
Poles, accidents during erection, 708
,, , A poles, 693
,, , ,, ,, , saddle wire, 696
,, , ,, ,, , use of, 694
,, , ,, ,, , use of blocks, 694
,, , and elements of cell, 20
,, , arming of, 703
,, , breaking stress of, 723
,, , buckling due to misplaced stays, 685
,, , ,, prevented, 690
,, , Burnetized and Boucherized, 661
,, , depth buried, 680
,, , diameter of, 679
,, , dimensions of, 678, 679
,, , distances apart, 679
,, , erection of, 703
,, , ,, ,, with derrick, 705
,, , ,, ,, ,, ,, , precautions, 708
,, , exudation of creosote, 681
,, , height of, 678
,, , H poles, 695
,, , ,, ,, , earth-wiring, 695
,, , ,, ,, , size of poles, 695
,, , in marshy ground, 681
,, , in rock, 680
,, , iron poles, 658, 697
,, , ,, ,, adapters for, 700
,, , ,, ,, carrying capacity, 698
,, , ,, ,, Chambers' joint, 700
,, , ,, ,, climbing clips, 737
,, , ,, ,, erection of, 701
,, , ,, ,, for roof standards, 737
,, , ,, ,, preservation of, 737
,, , larch, 658
,, , life of, 660, 661
,, , light, medium, and stout, 679

Poles, numbering of, 730
,, , number per mile, 679
,, , obstacles to be avoided, 727
,, , pitch pine, 658
,, , ,, ,, , treatment of, 659
,, , ,, ,, , used for roof standards, 737
,, , painting of, 659, 661
,, , preservative processes, 659
,, , red fir, 658
,, , seasoning of, 659
,, , strength of, 723
,, , tarring of, 659
,, , terminal, 658, 803
,, , timber for, 658
,, , trussing of, 690
,, , twisting of, 705
,, , wind pressure on, 679
Pomeroy's test of earth, 647
Porcelain, 664
Porous pot, 21
Positive electricity, 1
,, pole and plate, 20, 812
Potential, 2
,, at point due to charge, 3
,, divider, 141
,, , quantity, and capacity, 14
,, , unit of, 3
Potentiometer, 135
,, , modern types, 140
Power circuits, protection, 574
,, ,, , use of india-rubber gloves, 576
Press button, 605
Primary and secondary cells, 18, 428
Primary cells. *See* Bichromate, Clark, Dry, Daniell, Leclanché, and Sealed Standard
Printer, 173
Printing telegraphs. *See* Steljes, Hughes, and Murray
Protection. *See* Lightning, Power, and Fire
Punner, 706
Punning of earth, 702, 705

Q

Quadruplex, 267
,, adjustment of, 283
,, aids to memorizing connections, 281
,, A side relayed, 543
,, ,, ,, ,, path of current, 543
,, ,, ,, ,, , latest, 545
,, balancing, 283
,, battery coils, 279
,, ,, power, 287
,, B kick, 272
,, Bridging coil, use of, 285
,, B side, condenser arrangement, 276, 824, 853

Quadruplex B side condenser, latest, 853
,, ,, ,, , relaying sounder, 275
,, current required, 287
,, decrement working, 285
,, earthing switch, 279
,, effects of short circuit and disconnection in intermediate position of key, 280
,, faults in apparatus, 286
,, galvanometer for measuring currents, 509
,, increment working, 267, 285
,, resistance blocks, 280
,, Universal batteries, 283
,, various systems, 286
,, Wheatstone on A side, 289
,, working on very short lines, 285
Quantity of electricity static unit, 3
,, ,, ,, electromagnetic, 14
,, ,, ,, , potential, and capacity, 14
Quick-lime, 786

R

Radicles, 810
Railways, aërial lines on, 656
Reading condenser. *See* Shunted condenser
Receiver. *See* Wheatstone
Red lead, 431
Reed, 838
Reinstatement charges, 746
RELAYS :—
clearing relay, 420
coils in series or parallel, 206, 209
C type, 195
cut off relay, 422
D type, 190, 210
definition of 186
design of, 197
differential winding, 189
,, ,, test for, 197
double tongued, 548
line relay, 419
non-polarized, 186
,, ,, B, 188, 404
,, ,, indicator B, 404
object of, 186
polarized and non-polarized, 187
,, definition of, 191
,, indicator B, 405
P.O. Standard A, 191
,, ,, B, 194
,, ,, , adjustments, 204
,, ,, neutral, 194
,, ,, ,, adjustment of, 194
,, ,, resistance of coils, 194
self-inductance of, 16
Siemen's, 195
translating, 190, 420

RELAYS—*continued*
used in telephony, 189
weight of moving system, 198
Relaying sounder, 187, 275
,, ,, resistance of, 188
Reluctance, 76

REPEATERS, 512
adjustment of, 523
auto-switch, 520
Bridge duplex on cable side, 532
duplex, 526
,, switch, 528
faults and causes, 524
forked, 534
,, path of current, 535
Hughes', 541
position of, in circuit, 518
quadruplex, 546
simplex, arrangement of, 521
,, path of current, 522
,, principle, 518
theory of, 517
Residual magnetism, 166, 186, 189, 197, 539
,, ,, molecular theory, 804
Resistance, 11
,, coils, 105
,, ,, connections, 106
,, ,, metal cased, 489
,, ,, values, 106
,, ,, winding, 106
,, constant of galvo, 104
,, internal resistance of cells, 40, 143
,, lamp, 489
,, measurement of, 638
,, of batteries, 40
,, specific. *See* Resistivity
,, unit of, 11
Resistivity, 68
,, , length-weight, 72
,, , cubic, 69
,, of various substances, 68
Resultant force, 720
,, point, 684
Retardation coils, 108, 258
Retentivity, 166
Revolving wires, 663
Rheostat, 110
,, B, C, and D, 112
,, connections of C, 112
Ring bolts, 756
Roberts, M. F., 689, 695, 758, 794
Roberts' stay tool, 689
Roof standards, 736
,, ,, double, 740

Roof standards, large type, 740
,, ,, principles of construction, 736
,, ,, use of pitch pine, 737

S

Saddle stay, 695
,, wire, 662
,, ,, on A poles, 696
Safety belt, 576
,, factor of, 709, 722
,, valve (dry air), 790
Sag of wires, 709
,, ,, stress, length of span, 712
Salammoniac, 25
Salts, 811
Sealed standard cell, 124
,, ,, ,, resistance in box, 124
,, ,, ,, short-circuiting of, 124
,, ,, ,, use of, 122
Secondary cell working. *See* Universal battery system

SECONDARY CELLS, 428
acid resisting paint, 466
automatic cut out, 482
board separators, 440
buckling of plates, 435, 453
capacity in ampere hours, 431
charging of, 480
,, ,, provision of current, 481
chloride type, 436
,, ,, capacity of, 438
,, ,, charging and discharging rates, 438, 443, 450
,, ,, manufacture, 436
,, ,, R type, 438
,, ,, specific gravity, 438
connections between cells, 466
D.P. type, 436
electrolyte for, 451
E.M.F. of, 429
,, on charge and discharge, 450
E.P.S., 441
,, capacity, 443
,, discharge rate, 443
,, ebonite forks, 443
,, gravity, 443
,, K type, 441
,, W.S. type, 443
exide negative, 438
expansion of active material, 435
Faure types, 431
first charge, 451
,, ,, gravity during, 452
gassing of, 452
glass rod separators, 438
grids, 438

SECONDARY CELLS—*continued*
Hart type, 443
,, ,, capacity, 450
,, ,, discharge rate, 450
,, ,, ebonite separators, 449
,, ,, gravity, 450
insulators for, 451
internal resistance and temperature, 450
lead antimony grids, 437
milky appearance of electrolyte, 452
number of positive and negative plates, 435
principle, 428
size of cell required, 484
small type for metallic circuits, 823
sulphating of, 452
treatment of cells, 452
Self-inductance and time constant, 313, 319
,, ,, of galvanometer in series and parallel, 319
,, ,, of relays, 16
,, ,, unit, 16
Self-induction, 15, 202, 244, 513, 514, 520, 567
,, ,, balanced by shunted condenser, 314
,, ,, distributed and speed of working, 514
,, ,, retarding effect of in sending circuit, 319
Sellon, 441
Sending circuit, resistance of, 319
Sensitiveness of galvanometers, 104
Shackles, 667
Shunted condenser, 15, 313, 327, 500, 521
,, ,, action in balancing self-induction, 314
,, ,, ,, ,, Wheatstone working, 316
,, ,, ,, on short lines, 319
,, ,, adjustment of, 318
,, ,, quantity of electricity in condenser, 15
Shunts, 113, 120
,, ammeter, 461
,, box of, 119
,, coils on differential galvanometer, 235
,, compensating resistance, 117
,, joint resistance, 116
,, multiplying power, 114, 122
,, object of galvanometer shunts, 113
,, principle ,, ,, ,, 114
,, on single current galvanometer, 171
,, on sounders, 168
,, relations and rules of, 115
,, universal type, 120
,, ,, ,, , box, 122
,, ,, ,, , rule for, 122
Siemen's relay, 195
Signalling condenser, 325, 338, 823
,, , speed of. *See* Speed of working
Silencers, Caël Beau, 733
,, chain, 735
,, for aërial wires, 733

Silencers for brackets, 735
,, for standards, 737
,, N. T. Co., 734
,, sounder and circuit silencers. *See* Sounder and Circuit
Simultaneous telegraphy and telephony. *See* Superimposing
SINGLE CURRENT SOUNDER, 206
adjustment, 209
battery power, 209
current required, 209
faults, 208
path of current, 208
v. direct sounder, 209
duplex, 236
,, aids to memorizing connections, 244
,, balancing, 243
,, battery power and current, 245
,, faults, 243
,, intermediate position of key, 240
,, path of current, 237
,, on very short lines, 244
,, switch, 241
,, *See* also "Duplex"
SINGLE NEEDLE, 176
advantages of, 185
battery power, 185
coils, figure of merit, 179
,, Nealo's, 180
,, resistance of, 185
,, Spagnoletti's, 178
,, Varley's, 177
current required, 185
Skin effect, 513
Slide pipes, 749
,, ,, *v.* boxes, 750
Sling chains, 706
Slip for perforator, 292
Smith composition, 742
Snatchblock, 706, 780, 782
Soldering, 676
,, with resin as flux, 784
Solenoid, 76
,, magnetic force of, 76
,, to find N. pole of, 165
Solid bends, 745
,, plugs double, 759
,, ,, single, 794
,, ,, with G.P. tails, 795
Sounder circuits. *See* Direct, Single current, Double current, Sounder, Quadruplex
Sounder, 167
,, adjustment of, 168
,, 20ω, 168
,, 900ω, 462
,, magnetic circuit of, 165

Sounder, figure of merit of, 168
,, polarized, 416
,, relaying. *See* Relaying sounder
,, silencer, 536
Sounding pieces for needle dials, 179
Sourdines. *See* Silencers
Spacing current, 222
Spagnoletti's coils, 178
Span, length of, 679, 680
,, stress of wires, 712
Spark coils, 280
Sparking at relay contacts, 188, 202, 277, 523
,, of transmitter, 320
,, point, 321, 513
Special circuits, apparatus for, 501
,, ,, calculation of power, 627
,, ,, ,, ,, resistance, 627
,, ,, formation of, 626
Specific inductive capacity, 213
,, ,, ,, of substances, 214
,, gravity. *See* Secondary cells
,, ,, of copper, *footnote* 69
,, resistance. *See* Resistivity

SPEED OF WORKING, 512
and battery resistance, 513
,, distributed leaks, 514
,, ,, self-induction, 514
,, insulation resistance, 607
,, length of circuit, 517
on duplex circuits, 517
,, Hughes, 517
various types of line, 516
Speed point, 321
Spirit lamp, 783
Splicing tool for stays, 689
Split, double, 237
,, pipe, 750
Spring jack. *See* Switch-spring
Square, for telephone circuits, 663
Standard cells, 34, 37, 124, 126
,, ,, *See* Clark, Daniell, and Sealed standard cells
,, units, 13
,, wire gauge, 867
Standards. *See* Roof standards
Static electricity, 1
,, capacity. *See* Capacity
Stay, 681
,, at an angle, 720
,, attachment of, to pole and bow, 689
,, blocks, 682, 683
,, ,, depth buried, 683
,, ,, holes for, 683
,, bow and thimble, 682
,, crutch, 690

Stay, effect of misplaced, 685
,, factor of safety, 718
,, guards, 687
,, iron rods, use of, 689
,, lateral, 720
,, longitudinal or line, 728, 732
,, parallel stays, 687, 688
,, pole, 730
,, prevention of climbing, 689
,, proximity to line wire, 690
,, resultant point for fixing, 684
,, rod and bow, 682
,, ,, preservation of screw thread, 685
,, ,, ratchet nut, 682
,, rods, sizes of, 683
,, rules for size of, 719
,, splicing of, 689
,, ,, tool, 689
,, spread of, 682, 717
,, stresses on at T.P., 717
,, swivel, 740
,, tightener, 730
,, to standards, anchoring of, 740
,, use of pole spur, 690
,, V-stays, 683, 687
,, ,, on grazing land, 687
,, wire type and strength of, 682

Steljes' Recorder, 361
figure changing cam, 364
leak working, 369
printing electromagnet, 363
,, lever, 364, 365
slip feeding, 366
typewheel escapement, 362
unison arm, 368
Steps for manholes, 756
,, , pole steps, 696
Stevens' automatic, 328
Stone edging for boxes, 752
Storage battery. *See* Secondary cells
Stray currents, 628, 757, 761
Stress of wires, 712
Struts, 691
,, fitting of, 692
,, need for blocks, 693
,, tie bolt, 693
,, vertical guard for, 693
Subsidiary drum method of renewing G.P. cables, 797
Subterranean circuits, 823
Sulphuric acid, 810
Superimposing, 815
,, A.B.C. on telephone, 820
,, duplex on metallic circuit quadruplex, 766

Superimposing, Hughes on Paris trunks, 819
,, , ,, ,, ,, ,, , ringing on, 820
,, on telegraphic lines for rural telephones, 818
,, ,, multiple twin cables, 771
,, Steljes on telephone, 820
,, telegraph call wires, 820
,, ,, on trunks, 821
,, Van Rysselberghe, 815
,, with bridging coils, 819
,, ,, transformers, 817
Surveying for aërial lines, 726
,, ,, underground lines, 797
Sweeps' rods, 772, 777
Switch, automatic, 509, 510, 520, 856
,, 2-way, 279, 282, 288, 289, 324, 326, 340, 508, 542, 824, 855, 856
,, 4-bar, 508, 510, 824
,, 6- ,, , 534
,, 8- ,, , 528
,, 6-terminal 2 position, 241, 262, 323, 324, 327, 499, 503, 536, 606
,, 7- ,, 2 ,, 340, 504
,, 8- ,, 4 ,, 602
,, 9- ,, 2 ,, 493, 855, 856
,, Hughes, 391
,, peg, 502, 503, 511, 529
Switching systems. *See* Concentrator and London Metropolitan switching system
Switch spring, 403, 405, 419
,, ,, , 5-point, 405
Syllabuses of examinations, 865
Symmetrical twist system, 663
Synchronism, 826

T

TABLES :—
Air space *v.* G.P. cables number of wires in pipe, 760
Copper wire, 674
Iron poles, tubes forming, 698
,, ,, , ,, assembly of, 698
Iron wire, 673
Poles 30′, 40′, 50′ and 60′, 679
P.O. tangent galvanometer, 119
Resistivities, 68
Sags for copper and iron wires, 714
Shunted galvanometer 90°, 119
Specific inductive capacity, 214
Standard wire gauge, 864
Stay blocks, 683
Stresses on copper wire at various temperatures, 715
,, ,, iron wires at various temperatures, 716
Tapes and binders, 676
Tackle, 706
Tail-ending, 797
Tangent of an angle, 85
,, galvanometer. *See* Galvanometer
Tapes for copper wire, 676

Tarring of poles, 659
Telegraph call wire, 820
Telephones with telegraphs superimposed. *See* Superimposing
,, , twisted circuits, 663
Temperature and resistance of conductors, 74
,, ,, ,, ,, insulators, 75
,, variation of resistance for copper, 74
,, ,, ,, ,, of line wire, 262
,, ,, ,, ,, various metals, 109
Tensile strength, 671
Tension ratchets, 710, 711
Tents, 783
Terminal insulators, 667
Terminating pipes, 752
Terms, chemical 809

TEST BOARD, SWITCH SPRING TYPE, 560
changes, 564
cross-connecting facilities, 563
grouping springs, 564
intermediate returns, 565
looping strip, 565
principle of, 562
special circuits, 564
transfer circuits, 564

TEST BOX, 551
arrangement of, 552
battery panel, 553, 559
,, ,, crossing batteries, 559
,, ,, increasing power, 559
bunching wires, 564
crossing instruments and circuits, 556
detector. *See* Detector
disconnecting wires, 555
dividing a wire, 555
earthing wires, 555
forking wires, 556
forming a metallic circuit, 555
intermediate circuits, 554
joining through, 556
looping wires, 555
pillar, 750
reversing apparatus, 555
route labels, 554
small office type, 557
tapping circuits, 556
terminated circuits, 554
U-link type, 559
Test and cross-connection frames, 574, 585
,, ,, ,, ,, ,, fitting heat coils on, 583
,, cable, 778
,, holes, 800
,, hole tablet, 618

Test jacks, 585
Testing. *See* Battery testing, Localization tests, Eden morning test, Wheatstone Bridge
Thermometer, 713
Thomson, 98
Tie-bolts, 692, 693, 695
Timber, 658
Time, constant, 313
Tinfoil paper, 218
T-iron, 747
Transformer, 817
Transmitter. *See* Murray and Wheatstone
Transmitting relay, 522
Transom, 693,
Trenail, 696
Trenching, 747
Triangle of forces, 713
Tribe, 432
Truss rods and rings, 695
Type-printing instruments. *See* Steljes, Hughes, and Murray.

U

U-links, 559, 618, 800
Umschalter switch, 402
Underground fire-proof chamber, 584
,, lines, 657
,, ,, , construction of, 741
,, ,, , cost of pipe line, 746
,, ,, , efficiency, cost, and circumstances when used, 741
,, ,, , faults, 623, 798
,, ,, , surveying, 797
Unit B.A. and standard units, 13
,, Board of Trade unit, 17
,, capacity, 14
,, E.M.F, 11
,, force, 3
,, magnetic field, 6
,, ,, pole, 6
,, potential (static), 3
,, quantity of electricity (static), 3
,, ,, ,, ,, (electromagnetic), 14
,, rate of doing work, 17
,, resistance, 11
,, self-inductance, 15
UNIVERSAL BATTERY SYSTEM, 454
battery racks, 465
,, room, 464
Circuit Alterations, 486
bridge duplex, 505
direct sounder, 492
,, writer, 492
double current sounder, up and down, 494
,, ,, ,, intermediate, 495

UNIVERSAL BATTERY SYSTEM—*continued*
Circuit Alterations—*continued*
double current sounder, duplex, 496
,, plate sounder, 490
,, ,, ,, intermediate offices, 491
,, ,, ,, summary of, 491
duplex, 505
,, special circuits, 504
single current sounder, 491
,, ,, ,, duplex, 493
,, ,, ,, duplexed permanently, 494
single needle, 487
,, ,, summary of alterations, 489
,, ,, commutator, 488
principle of, 486
quadruplex, 505, 856
,, with Wheatstone on A, 509, 857
test box speaking set, 511
Wheatstone terminal station, 500
,, special circuits, 501
,, special circuits, test box connections, 502
complete set of cells, 463
cords for fuse case, 475
distribution and fuse case, 464, 474
divided battery, necessity for, 456
fuses at cells, 466
,, , general scheme of, 464
,, , principle of application of, 466
main and 24^{v} sets, composition of, 462
,, charging switch, 469
,, distributing cabinet, 464, 470
,, sets, arrangement of, 462
,, switch, 464
original installation, 476
,, ,, , charging arrangements, 479
,, ,, , distribution, 478
,, ,, , distributing tablets, 478
,, ,, , main switches, 476
,, ,, , reverser, 476
plate sounder coils, 491
percentage variation of current formulæ, 458
positive and negative switch, details of, 467
principle of, 454
resistances in power leads, 489, 506
sizes of cells required, 484
sounders 900$^{\omega}$ necessity for, 462
switch cabinet, 464, 467
theory of, 457
uniformity of work on cells, 463
voltages provided, 461
with Primary Cells, 511
Up and down stations, 170, 184, 202
Uprighter. *See* Relaying Sounder
Up station, 170

V

Vacuum protector, 570, 800
Van Rysselberghe, 815
Variable lay, 767, 770, 771
Varley's needle coils, 177
,, loop test, 644
Volckmar, 441
Volt, definition of, 12
Voltaic cell, 7
,, electricity, 7
Voltmeter, 459

W

Wade, 435
Wall plate, 740
,, strap, 740
Watt, definition of, 17
Wayleave, 656
Weather contact, 678
Weight per ohm-mile, 71, 627
Weston voltmeter, 460
Wet rot, 659
Wheatstone A.B.C. *See* A.B.C.
WHEATSTONE AUTOMATIC SYSTEM, 291
adding transmitter to key worked circuit, 322
battery power, 326
,, resistance coils, 323
differential duplex with signalling condensers, 325
duplex, 323
,, alterations on duplex switch, 323
news circuits, 326
perforated slip and received signals, 303
perforator, 291
,, adjustment of, 297
,, operation of punches, 292
,, paper feeding, 293
,, pneumatic, 298
,, punches, 295
,, Willmot's improvements, 295
receiver, 291, 308
,, adjustment of, 312
,, bell, 311
,, double slip drawer, 311
,, figure of merit, 313
,, inking arrangements, 309
,, motive power, 310
,, motor, 311
,, speed of slip, 313
,, train, 311
,, spring driven, 313
,, substituted for relay, 323
,, winding of coils, 312
resistance coil in receiver circuit, 325
transmitter, 291, 299

WHEATSTONE AUTOMATIC SYSTEM—*continued*
transmitter, action of in signalling a word, 302
,, , ,, ,, summarized, 304
,, , ,, ,, fans, 306, 307
,, , arrangement of rods, 300
,, , bias on, 305
,, , bolting of, 308
,, , divided lever, 299
,, , jockey wheel, 302
,, , magnetic bias type, 304
,, , motive power, 300
,, , speed of slip, 308
,, , star wheel, 301
,, , stopping and starting lever, 307
,, , switch, 321
,, , variable speed gear, 305
,, , Willmot's magnetic bias, 304
WHEATSTONE BRIDGE, 631
example of a test, 638
individual resistances of 3 or more looped wires, 641
insulation of testing battery, 640
measurement of resistance having capacity self-inductance, or an E.M.F., 639
periodical conductor resistance tests, 643
P.O. type, 634
practical use of, 636
proof of principle, 632
proportionals chosen, 637
resistance of earthed circuits, 640
reversing switch, 640
testing with false zero, 641
tests for which used, 149, 639, 641, 643, 644, 645, 647
Whitening, 761
Willmot, J. W., 295, 304
Winch, 780
Wind and water line, 659
,, pressure, 722
Winding, differential, 91
,, , double, 112
Wiped joint, 787
Wire, breaking stress of, 669
,, , bronze, 669, 674
,, , ,, copper and iron choice of, 669
,, choice of materials and gauge for lines, 669
,, ,, ,, ,, ,, ,, ,, resistance coils, 109
,, copper, for aërial lines, 673
,, ,, binding in, 675, 676
,, ,, ductility, 673
,, ,, electrical properties, 674
,, ,, expansion coefficient, 713, 717
,, ,, form, 673
,, ,, gauge of, 670, 674
,, ,, jointing of, 676
,, ,, table of sizes, etc., 674
,, ,, tensile strength, 674